The Open University

S102PRP MODULE 8 INTO SCIENCE

MODULE 8 ENERGY

STUDY GUIDE

This Module shows you how important the concepts of 'energy' and 'energy conversion' are in science. You will meet one of the most fundamental laws of science—the Law of Conservation of Energy—and you will also become fluent in using the SI unit of energy, the joule. Because ideas about energy crop up in all branches of science, this Module will draw together some ideas from earlier Modules.

Sections 2 and 4 contain some very short experiments that require only small household items. In Section 3 you are asked to do an investigation involving heating up a saucepan of water and measuring its temperature. To do that you will need ordinary kitchen facilities and a thermometer. Any thermometer that is calibrated up to 100 °C or beyond will do—for example, a jam-making thermometer. These cost about £9 and are obtainable from many hardware shops. If you have nothing suitable, are unable to borrow one and want to avoid the expenditure, experimental results are provided in the text. *Do not use* a clinical thermometer; it would be destroyed by water temperatures above about 40 °C.

The other main aim of this Module is to introduce you to *algebra*—the branch of mathematics that makes use of letters that stand for numbers. This is an exceptionally important mathematical 'tool' in science. Section 7 in this Module is devoted entirely to algebra and your study of this long Section may take as much as half the total time allowed for the entire Module. Many of the examples used to explain the algebra are based on the preceding Sections about energy. So, do not attempt the algebra part before reading the earlier part of the Module (including the investigation in Section 3). There is some graph drawing, some calculator work and some work on powers of ten—more practice of skills from earlier Modules.

One last point. This Module is quite hard in places and is moderately long; about 8 hours study time (including the experiment) may be needed.

1 INTRODUCING ENERGY

Imagine that you have just woken up. Perhaps it is a holiday and there is no rush. You lie still and look around you. What do you see that tells you the room is real and not just a colour photograph? Above all, you will see movement: the breeze moving the trees outside; a bee on the window pane; steam rising from a cup of tea; the movement of your own limbs. As well as movement, you'll feel the warmth of your body and of the sunlight falling on the bed. You'll also see the light from the Sun and perhaps from a nearby lamp. You'll hear sounds: the drone of the bee; voices near by. Finally, movement again as you galvanize your muscles and force yourself to get out of bed and move across the room. All these things are manifestations—observations through our senses—of **energy being converted from one form to another**.

The concepts of energy and energy conversion are very much part of everyday speech and everyday thinking. 'Put a bit of energy into it!' is a common enough thing to say to someone digging, lifting or cycling. The idea that coal, oil, hydro-electricity or wind has much to do with energy is taken for granted in newspaper articles or television chatter. The idea that food provides energy is routine in advertisements for chocolate bars and glucose drinks. So also is the idea that food energy can be converted into movement: 'I'll have to run a mile to work off that cake … '.

But there is a gulf between this kind of vague awareness and a proper scientific appreciation of the nature of energy. To achieve a fuller understanding, energy has to be *defined* and it has to be *measured* in appropriate units.

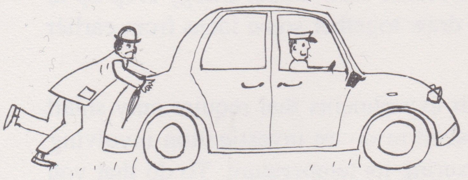


FIGURE 1 Chauffeur-driven to work in the City! But how much energy is needed to start the car?

What, precisely, *is* **energy**? To help us find a usable definition, look at Figure 1. You are probably aware that the man struggling to push-start the car is using energy from his muscles to make the car move. Put into the technical jargon of physics—as he pushes it, he is said to be *doing work* on the car. The precise definition of **work** doesn't matter in this Course but it is similar to the everyday meaning of 'getting some change to occur as the result of effort'. Picture a few other scenes to get hold of the idea: a crane does work on a crate by lifting it; a locomotive does work on the coaches attached to it by pulling them along the rail track; wind does work by turning the sails of a windmill, etc. Although this way of putting it may be new to you, these examples should help you to understand what scientists mean when they say that:

energy is the capacity to do work

In earlier Modules you have met a number of different SI units. Metres, kilograms and seconds are the basic ones, with many others derived from and based on these. For example, speed and acceleration—given in the table on the back cover of Module 2—involve the units of both distance and time. Energy is also listed in that table; its SI unit is the **joule**, abbreviation J, and pronounced as 'jewel' (as in ruby or diamond). More will be said about what joules actually are in Section 5. For now, just *accept* that:

energy is measured in units called joules

Making use of this new term is immediately useful—and makes for easier understanding. Which would you prefer to do, push-start a mini or a large van? You would no doubt choose the mini—it is much lighter and would take far less energy to get it moving. In fact, if the right kind of measurements were made, we could express the energy needed in each case *in precise numerical terms*. For example—depending on how far and fast you have to push the vehicles—it might take around 3 000 joules to start the mini, and perhaps 6 000 joules to start the much heavier van. Note that these figures are rough estimates only, but they do emphasize the idea that energy is a quantitative thing that can be measured and has real units. By the end of the Module, you should be as comfortable with the use of joules as you now are with kilograms and metres.

2 THE INTERCONVERSION OF DIFFERENT FORMS OF ENERGY

You met some examples of one form of energy being converted into another in the waking-up scene of Section 1. You met another example when you considered push-starting a car—and again in the description of cranes, trains and windmills. Let us look into this idea of different forms of energy and their interconversion more carefully.

Let's begin with an analogy: money. Money comes in many forms that are all interconvertible. Someone going on a world tour might draw £10 000 from the bank. As the journey progresses, some would become French francs, some dollars, some pesetas, etc. If the traveller visited Hong Kong or the markets of Saudi Arabia, she might transform some of her money into small gold bars to bring home again. If she visited some isolated corner of the world, she might find that the local currency is salt or rare shells. All of it is money—recognized 'units of purchasing power'—but all of it is in different forms that can readily be converted from one into another.

Like money, energy exists in a range of different forms, all of which are interconvertible. What are these various *different forms* of energy and what interconversions commonly occur? One way to explore these questions is to do some short experiments.

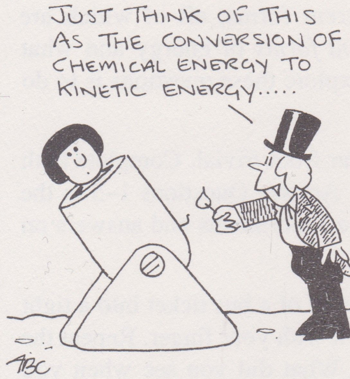
The two experiments that follow are simple but far from trivial. Complete both and write down your observations in the margin. Answer Questions 1–5 in the spaces provided. You will find a discussion of the experiments and answers on pages 4 and 5.

Experiment 1 Screw a piece of paper about the size of a bus ticket into a tight ball. Put it onto the table in front of you and flick it with your finger. Repeat the experiment, flicking more vigorously this time. What did you see when you flicked the paper ball? What did you hear? Now answer these questions:

> *Question 1:* You did work on the ball with your finger. Immediately after you had flicked the ball, what kind of energy did it have? You may not know a technical term for this, in which case just write a few words explaining your idea. If you hadn't thought of the moving ball as having any energy, picture a moving cannon ball made of iron!
>
> *Answer:* ....
>
> ....
>
> *Question 2:* Where do you think the energy of your flick came from? (Hint: think back to Module 7.)
>
> *Answer:* ....
>
> ....

Experiment 2 Put a sheet of paper flat on the table in front of you—ordinary A4 will do. Hold the paper steady with one hand. With the other, rub one finger to and fro on the paper while pressing down fairly hard (but not so hard as to ruck or move the paper). Do this as fast as you can for a few seconds. Put the tip of that finger to your lips: what do you notice about its temperature? What did you hear as you did the experiment? Repeat the experiment several times, rubbing faster and harder. Again, what do you notice about your finger temperature? What about the temperature of the paper where you have been rubbing? If you cool the other hand under a tap and then feel the skin over the muscles of the arm that you used for rubbing, what do you notice?

> *Question 3:* What everyday term would you use instead of the stars in this sentence: 'When ★ is given to an object, it gets hotter; when ★ is lost by an object, it becomes colder.'?
>
> *Answer:* ....
>
> *Question 4:* Bearing in mind how the temperature of the paper changed when you rubbed it, in what way does the amount of ★ it possesses *change* as it is rubbed? (Note that the star represents the same word as it does in Question 3.)
>
> *Answer:* ....
>
> *Question 5:* In fact, ★ is another form of energy—as we will discuss shortly. Bearing in mind that rubbing your finger caused the temperature of the paper and your finger tip to rise, where do you think that energy came from? (Note that the star once again represents the same word as before.)
>
> *Answer:* ....
>
> ....



Now that you have completed the experiments and answered the questions, what conclusions can be drawn about the different forms of energy involved and the ways in which one is converted to another?

Regarding Question 1, the moving paper ball has energy simply because it *is* moving; the technical term applied to this is **kinetic energy**. Cannon balls, cricket balls, avalanches and torrents of water have plenty of it. Even a single molecule in air has a some kinetic energy, albeit a very small amount. Once again, this is because the molecules (of oxygen, nitrogen, water and so on) are *moving* around, rather like very small cannon balls.

Question 2 focuses on the source of the energy that was given to the paper pellet. Some of the **chemical energy** of the fuel within the cells of the muscles of your flicking finger was converted to the kinetic energy of the paper pellet. In Module 7, you met the process of *aerobic respiration*. This, you may recall, is the name given to the reactions inside cells by which fuels such as glucose are converted to carbon dioxide and water. The overall reaction is represented by the chemical equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

and is the principal way in which energy is made available for the paper-flicking.

The second experiment introduced you to yet another form of energy namely **heat energy**. The shorter and more everyday term for this is simply heat—and this is the star (★) in Question 3. When your moving finger rubs on the paper surface, much of the kinetic energy of the moving finger is converted, as a consequence of **friction**, into heat. The increase in the amount of heat in the paper leads directly to an increase in temperature (Question 4). Friction, the drag that one surface exerts on another as they move against each other, is a very common and important phenomenon. Whether in the bearings of rotating wheels, in drilling into wood or in rubbing a piece of paper, friction always leads to the conversion of kinetic energy into heat.

Question 5 asks you to consider where the kinetic energy (and hence heat energy) in Experiment 2 came from. Once again, the answer is from the chemical energy of the fuels within the muscles.

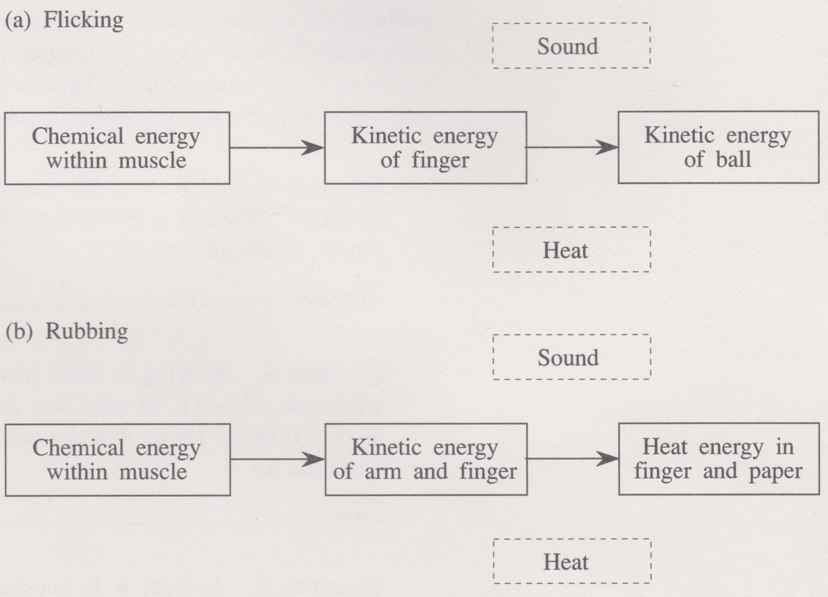


FIGURE 2 Energy conversions in Experiments 1 and 2.

Now that three forms of energy have been identified (chemical energy, kinetic energy and heat energy) we can begin to construct a diagram that shows how one form changes into another in Experiments 1 and 2. Look at Figure 2. This shows—in the boxes with solid lines—the energy conversions discussed so far; ignore the dotted boxes for the moment.

Now think carefully about what else is going on in these two experiments. There are other energy conversions that have not yet been entered on the diagram. The next few paragraphs ask you to think more about these conventions, and to make additions to Figure 2 so that it is complete.

When the paper pellet lands on the table, that too becomes very slightly warmer—the kinetic energy of the ball is converted to heat. If you find that hard to believe, think how warm a nail becomes when hammered. *Draw an arrow in Figure 2a to show the energy conversion involved when the ball lands on the table.*

Next, recall that you felt the temperature of the muscle that did the flicking and rubbing. It was warm. Heat is always a by-product of muscular effort. This is very obvious if you run or move vigorously for any length of time. Indeed unless the body gets rid of this heat, overheating would result—and this is why exercise leads to noticeable sweating. As far as muscle is concerned, only part of the energy released in equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

becomes kinetic energy. The rest (often more than half of the total) appears as heat. *Draw arrows in Figures 2a and 2b to show this type of energy conversion.*

Incidentally, if you exercise for a long time, your muscles may be forced—through lack of oxygen—to switch to *anaerobic respiration.* As you saw in Module 7, yeast converts glucose to alcohol under these circumstances. We do not! In fact glucose is anaerobically converted to a substance called lactic acid. This acid builds up in anaerobic muscles leading to discomfort and cramp. You may have felt that in your arm if you rubbed long and hard enough in Experiment 2.

What else did you observe that has not yet been discussed? You *heard* things in both experiments—the flick itself, the slight sound of the pellet landing, the noise of rubbing. What do these observations mean? In both experiments, some kinetic energy of moving objects is converted to **sound energy**. If you picture standing next to a large drum or gong that is being struck vigorously, then the idea of kinetic energy being converted to sound energy is very believable! *Draw arrows in Figures 2a and 2b to show this type of energy conversion.*

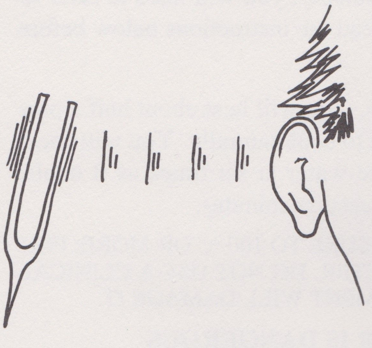


FIGURE 3 Sound waves from tuning fork to ear. A vibrating fork vibrates air which vibrates the eardrum.

You will find more details about sound in the following Box.

SOUND ENERGY
Although we are using the term 'sound energy', it is in fact a particular kind of kinetic energy. You remember from Modules 5 and 6 that gases are composed of relatively widely separated molecules moving freely in space. Air, a mixture containing mainly the gases nitrogen and oxygen, is no exception. When a sound is generated by some vibrating surface such as a tuning fork, piano string or vocal cord, neighbouring molecules in air are squashed together (compressed) and pulled apart from each other (rarefied) and the effect travels away from the source as a sound wave. The kinetic energy of the tuning fork is passed to the air molecules, the kinetic energy of these makes the membrane of the eardrum vibrate in the same way—and the note is heard within the brain. Look at Figure 3 to see this in diagrammatic form. Figure 4 shows in outline how you could demonstrate this 'possession of kinetic energy by sound waves' to yourself. No experimental details are given here—except to note that the powders that work well are cocoa or Bisto. If you want to try it, have a go—but don't count it in your study time!

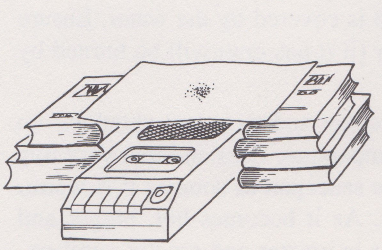


FIGURE 4 Outline of how to show sound has kinetic energy. The paper, making a bridge between two supports, must not *touch* the speaker. Use loud deep music. Organ music is ideal!

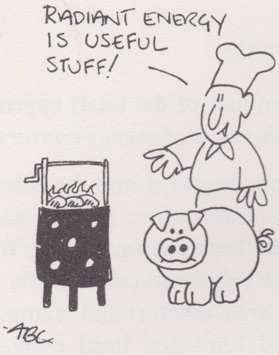
Now that you have completed the whole exercise by adding to Figure 2 all the arrows that seem sensible, look at our version of the completed diagram in Figure 13 in Appendix 2.

This Section has introduced chemical energy, kinetic energy, sound energy and heat energy. There is more to say about heat energy—in Section 3—and several more kinds of energy will be introduced in Section 4. Try SAQs 1 and 2 to test your understanding so far.

SAQ 1 In which three situations is chemical energy being converted to other forms? You will need to apply general knowledge.

(a) a spinning coin slowing (b) a log fire burning (c) a torch shining
(d) a grandfather clock ticking (e) rain falling (f) cress seed sprouting

SAQ 2 In which situations in the list in SAQ 1 is heat liberated? (This time you are not told how many to look for.)



3 MORE ABOUT HEAT

The major aim of this Section is to explain that there are two kinds of heat. One is the 'hotness of things'—such as the warmth in paper, fingers, water and air. The proper name for this kind of heat is **internal energy.** The other kind of heat is the kind that can travel across distances without warming up the space or air in between. The heat of the Sun is an obvious example but there are others you will come across. This kind of heat is called **radiant heat.**

3.1 A COOLING CURVE FOR WATER

Experiment 3 The main aim of this experiment is to help you learn more about heat. As it involves drawing a graph, you will also practise again the graph drawing skills that you met in Module 7. Additionally, you will need to refer to the graph in the Section dealing with algebra. Read the instructions below before starting the experiment.

The practical work itself takes about 45 minutes. You will heat about half a pint of water to boiling on a cooker and then allow it to cool naturally. You will use a thermometer to measure the temperature of the water at set times as it cools. You will also need a clock or other timer that measures minutes.

USE A THERMOMETER THAT CAN MEASURE TO 100 °C OR MORE: FOR EXAMPLE, A JAM-MAKING THERMOMETER. DO NOT USE A CLINICAL THERMOMETER BECAUSE THE EXPERIMENT WILL DAMAGE IT.

TAKE CARE: BOILING WATER IS DANGEROUS

Procedure

(1) Put half a pint of cold water (about 300 cm^3) into a small saucepan.

(2) Place the thermometer in so that the bulb is covered by the water. Ensure that no plastic parts of the thermometer holder (if it has one) will be burned by the cooker.

(3) Put the saucepan on the burner of your cooker and turn the lighted gas on full (or the power up high). Notice that the temperature rises and that very tiny bubbles are formed on the inner surface of the saucepan as soon as it is warm. This is dissolved air coming out of solution. As it becomes hot, bigger and bigger bubbles—water vapour not air—appear in greater and greater numbers. Note that when it begins to boil, the temperature is 100 °C and never[1] gets higher even when boiling vigorously.

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[1] But this is true only if the water is pure and at ordinary pressure. When things are dissolved in it—sugar in jam-making, for example—it boils at a higher temperature. If pressure is increased (as in a pressure cooker), water also has a higher boiling temperature.

(4) As soon as the water boils, lift the pan away from the heat and place on a cold surface. Immediately make a note of the time on your clock and the temperature of the water. This time is taken as zero in Table 1 and you should enter your actual temperature in the empty space in the first row.

Note that our results have already been entered in Table 1. Your results will probably differ from ours. Do not worry about this; reasons for any differences are discussed below.

(5) Now, *without stirring*, read the temperature of the water every minute for the first 15 minutes and then every 5 minutes for the next 15 minutes. Record your results in Table 1.

(6) As the water cools, hold your hand close above the surface (*careful*). Cool your hand under a tap to make it sensitive to heat again—and hold the back of your hand (the more sensitive part) about a centimetre away from the metal *side* of the saucepan. Note what you felt in both cases.

TABLE 1 Results for Experiment 3.

Time/ minutes	Temperature/ °C (ours)	Temperature/ °C (yours)	Time/ minutes	Temperature/ °C (ours)	Temperature/ °C (yours)
0 (start)	100		10	56	
1	90		11	53	
2	84		12	51	
3	78		13	50	
4	72		14	48	
5	69		15	46	
6	66		20	40	
7	63		25	35	
8	60		30	31	
9	58				

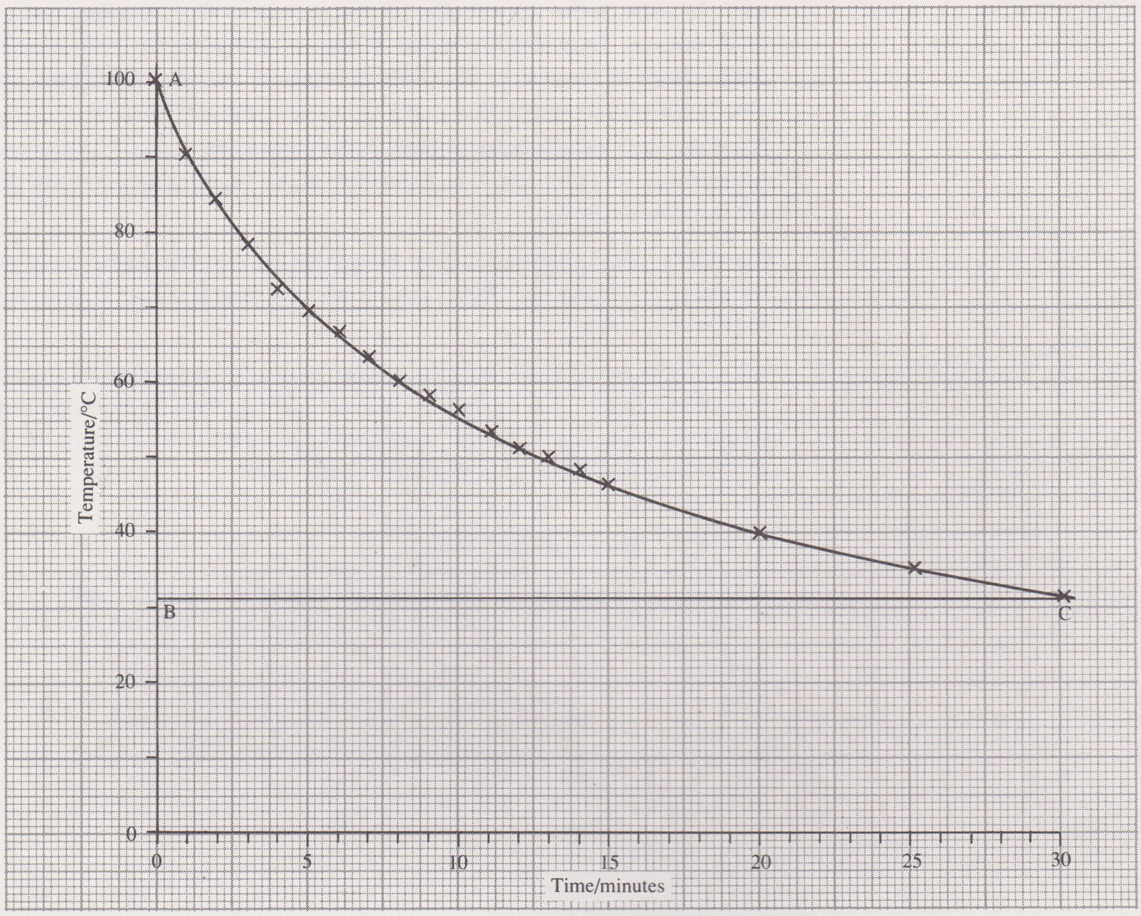
Now plot your data on the graph paper in the bottom part of Figure 5; our results are plotted at the top. Normally you would have to choose what scale to adopt to make the range of your measurements fit the paper. This time you have it easy: just copy the scale adopted in the top graph—but ask yourself whether you *could* have done it unaided.

□ What scale would you have chosen if you had made measurements over one hour?

■ In Figure 5 we have used four small squares for one minute. As you see, the '30 minutes' point is well over to the right. To fit 60 minutes on, you would need to use two small squares per minute.

Before we discuss the graphs, look back at Modules 5/6, Section 5.1 (especially Figure 26) and read again what is said there about the three forms of water. Modules 5/6 say:

> 'The molecule (H_2O) of water is the same whether the water is a liquid, solid or a gas. What does differ between the three forms is the closeness of the individual molecules to each other. …The temperature determines the closeness of the molecules … . With more heat the water molecules move even further apart and become water vapour'



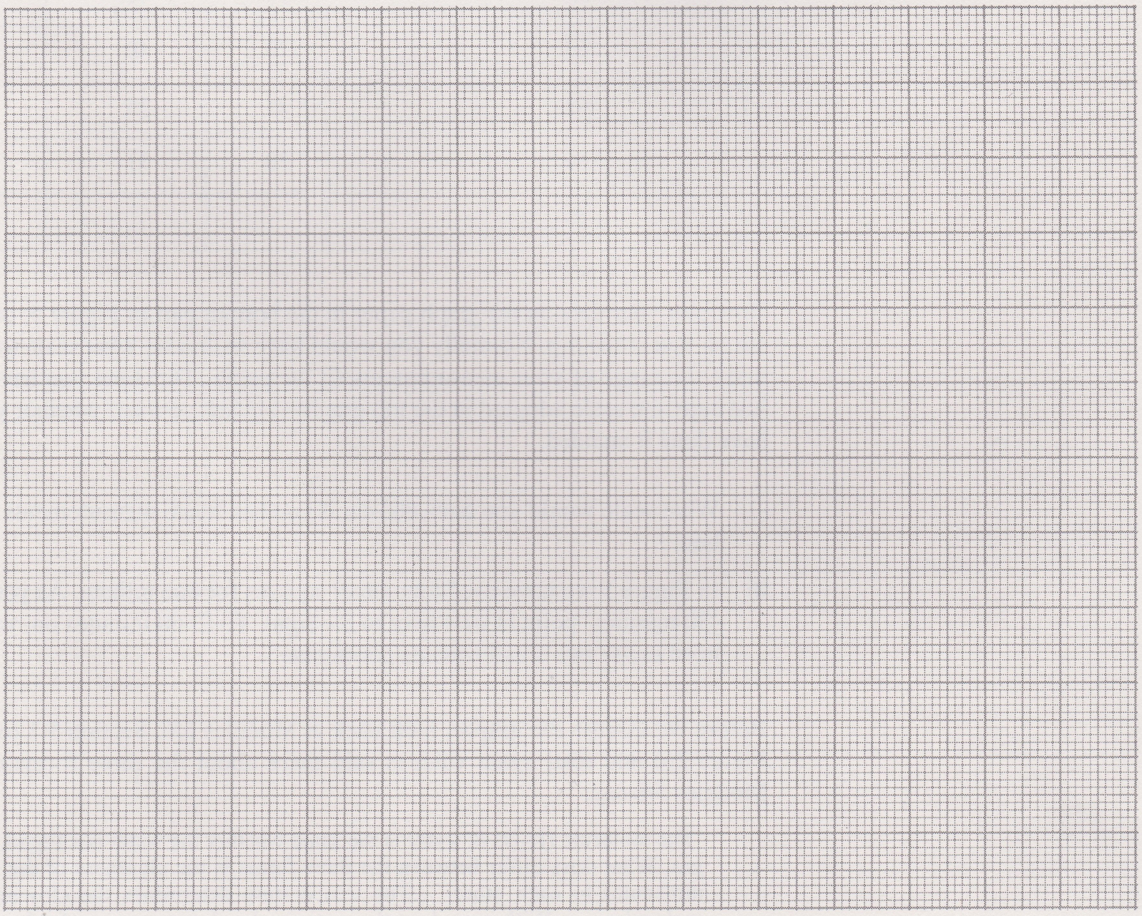


FIGURE 5 A plot of temperature against time for cooling water. Top: our results. Bottom: plot your results here. Points A, B and C are discussed in Section 3.2.

As you heat the water in Experiment 3, the heat energy entering the saucepan from the burner causes the molecules in water to move progressively faster and faster—they have more and more *kinetic energy*. These water molecules bombard the glass molecules of the bulb and pass on their kinetic energy to the glass by molecular collisions. The energetic glass molecules now have their effect on those of the substance (coloured alcohol) in the bulb and stem of the thermometer. These, too, get faster and move further apart from each other. This causes the liquid to *expand*—pushing the level up the tube and registering the temperature. As more heat is put in, the kinetic energy of the water molecules increases and the temperature goes on increasing. Incidentally, if you have a small mass of water, less heat will be needed to raise its temperature than if you have a larger mass. This is what one would expect—there are fewer molecules to be speeded up. For the same reason, a larger mass of water takes longer to cool down; this is why we advised a small saucepan and half a pint!

□ What happens to water molecules when water boils? From your observation of what happens to the temperature as the water boils, what do you think is happening to all the energy that is still pouring into the saucepan through the gas/electricity burner?

■ The molecules abruptly leave the liquid and spread out as a gas—water vapour. As the temperature never goes above 100 °C, it *must* be the case that all the energy entering the vessel is used in 'unsticking' the relatively close water molecules from each other as they leave the liquid state and become a gas.

The cooling part of the experiment also illustrates the way in which kinetic energy is involved in heat and temperature. The burner has been turned off and the saucepan removed, so no more energy enters. The hot (hence fast-moving) molecules of water pass their kinetic energy on to molecules in the air. These are slower, cooler molecules which, as they collect heat from the water, move faster themselves. In short, kinetic energy is transferred from the water molecules to the molecules in air. So heat is lost from the water and its temperature falls. Heat is gained by the air and its temperature rises. You felt this when you held your hand over the hot liquid. The transfer of heat is brought about by the difference in temperatures (hence the difference in kinetic energies) of the air and water molecules.

Now try to do this ITQ, using the necessary bits of knowledge dotted around the preceding paragraphs.

□ If your table of results and hence your cooling curve is slightly different from ours (and if it isn't, suppose that it is!) what reasons can you suggest for this difference?

■ There are several possibilities. You may have had more water or less water than us; you may have had a saucepan of different dimensions hence a different surface area; the saucepan may have had a different mass or been made of different material. Finally, your kitchen may have been warmer or colder than ours.

There is an important scientific term that you should now be able to appreciate. The name given to the kind of heat that is influenced by the kinetic energy of the molecules or atoms in a substance is the *internal energy* of the substance. The reason for the name should be clear—this kind of heat *is*, in effect, the internal kinetic energy of the molecules and atoms within it.

But what about the other kind of heat? As noted at the beginning of Section 3, it is called *radiant heat*. To understand what radiant heat is, we

need to remind ourselves about some ideas introduced in Module 4. In Figure 5 of that Module, you met the idea that light consists of waves of different wavelengths. That Figure is reproduced here as Figure 6, which you should look at now.

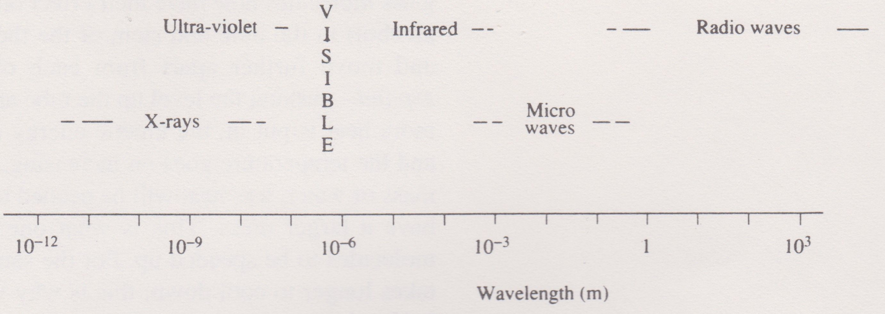


FIGURE 6 The electromagnetic spectrum. Note that visible light is only a small part of the spectrum.

The word *light* is usually used to describe the few wavelengths we can actually see—namely, the colours of a rainbow. Frequently, even though they are completely undetectable by our eyes, ultraviolet and infrared are also described as 'light'. However, many other wavelengths of radiation exist—and the whole lot is collectively known as the **electromagnetic spectrum**. In fact, *radiant heat* is simply part of the electromagnetic spectrum, in particular infrared and microwaves. If film sensitive to infrared[1] is loaded into a camera and put into a room that appears totally dark to our eyes together with a hot electric iron, it is perfectly possible to take a photo which shows the room clearly. The beam of infrared radiation (the radiant heat of the iron) is simply equivalent to a beam of light to the special film.

You can now apply these ideas to the saucepan of hot water. Because it is hot, it loses heat to its surroundings. Some of that heat is radiant heat and some of it immediately heats up the air around it—that is, it gives it internal energy. You sensed the radiant heat being lost when you held the back of your hand near to the side of the saucepan.

3.2 SOME CALCULATIONS BASED ON THE GRAPH

This short Section is not specially relevant to the main theme of energy. Its purpose is to introduce you to the technique of determining rates from graphs.

The **rate** at which something happens is the amount of change, in that something, per unit time. A rate can be an *average* one over a long period or an average over a much shorter period.

You can get the idea from a situation involving money. For example, if you spend your income of £10 000 over one complete year, your rate of spending per week, *averaged over the whole year*, is:

£10 000 ÷ 52 = £192.3 per week (to one decimal place)

If you had spent £1 500 of that in the four weeks of April, your rate of spending per week, *averaged over the month*, would have been:

£1 500 ÷ 4 = £375 per week

[1] As you can see, infrared radiation is sometimes called 'light' and sometimes called 'radiant heat'. Both are true: to the film it is light, to your hand held near the iron it is radiant heat.

If you had purchased a washing machine and other goods together totalling £500 on the 4th April, then your *weekly* expenditure rate *for that one day* would have been:

$7 \times 500 = £3\,500$ per week

That means if you had *gone on* spending at the rate you did on 4th April, you *would have* spent £3 500 in the one week!

Now let us look at rates of cooling. We can get the average rate of cooling over the half hour period of the experiment without bothering with the graph at all! Look at the table of results. The water cools from 100 °C to 31 °C in 30 minutes. This is a drop of 69 °C in 30 minutes. So, dividing 69 by 30, we get 2.3 °C per minute for the average rate over half an hour. We will write this in proper scientific notation, avoiding the word 'per', as 2.3 $°\text{C}\,\text{min}^{-1}$.

You can also work out the average rate over half an hour from our graph. Look at line AB. This shows the temperature fall over the whole half hour. Look at line BC. This shows the 30 minutes in this period. By dividing the number of degrees represented by AB (= 69) by the number of minutes represented by BC (= 30), the average value (in $°\text{C}\,\text{min}^{-1}$) is calculated (= 2.3, as before). Notice that you are dividing the appropriate vertical distance (in the correct units) by the appropriate horizontal distance (in the correct units).

□ Have a go at working out, from the graph of our data, the average cooling rate in $°\text{C}\,\text{min}^{-1}$ over the first 20 minutes of the experiment. Using the graph, draw a vertical line up from the 20 minute position on the bottom axis until it touches the curve. Now draw a horizontal line across from the point where it touches the curve to the vertical axis. Read off the temperature. Subtract this value from 100 and you have the temperature drop over the 20 minute period.

■ The horizontal line crosses the temperature axis at 40 °C. So the fall in temperature is $100 - 40 = 60$ °C. Thus the average rate of cooling over the first 20 minutes is 60 divided by 20 which equals 3 $°\text{C}\,\text{min}^{-1}$.

You will meet rates in later Modules. Now try SAQs 3 to 5.

SAQ 3 Suppose Experiment 3 had been done with a litre of water instead of 300 cm^3. What effect would this have on the temperature after 30 minutes of cooling—compared with your results and ours? Explain your answer in terms of kinetic energy.

SAQ 4 Mary finds that the experiment in her kitchen gives a cooling rate of 6 $°\text{C}\,\text{min}^{-1}$ at 70 °C compared with a result of 4 $°\text{C}\,\text{min}^{-1}$ for another student, again obtained at 70 °C but this time in a different kitchen. The second student, who had used an identical saucepan, comments that the reason this was so high was that Mary may have had much less than half a pint of water. 'No', Mary says 'on the contrary, I had slightly more'.

What other explanation could the second student have suggested? Explain your answer in terms of kinetic energy and temperature loss, making sure that you use the correct units.

SAQ 5 Using our results, what is the average cooling rate, in $°\text{C}\,\text{min}^{-1}$, over the period '18 minutes after the start' to '28 minutes after the start'?

4 MORE FORMS OF ENERGY AND THEIR INTERCONVERSION

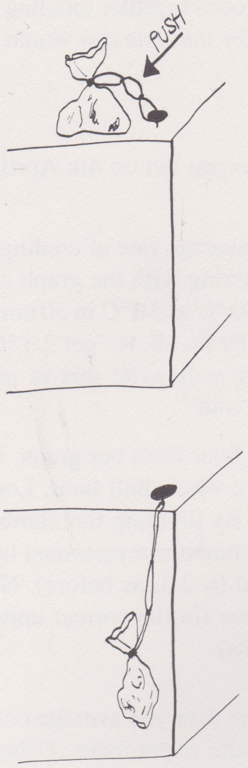


FIGURE 7 Equipment and its arrangement for Experiment 6.

From the previous Sections, you know about a number of different forms of energy and their relationship to each other. There are a number of others which you have yet to meet. Do the following short experiments; each takes only a few minutes. Look out for types of energy that you already know about—kinetic energy for example—and try to spot new types that the Module has not yet discussed. Write down in Table 2 which *forms of energy* you think are involved in each experiment. Underline any kinds of energy that you think have not been discussed in earlier Sections—inventing names to describe your ideas, if necessary. The energy types for Experiment 4 have been entered already as an example.

Experiment 4 Strike a match and put it in a dry saucer. Let it go out safely by itself. Note what you see, hear and (very carefully) feel.

Experiment 5 Put ten or so fifty pence pieces (or anything of a broadly similar mass) into a small paper or plastic bag. Put the bag near the edge of your table then push the bag over the edge. Note what you see and hear.

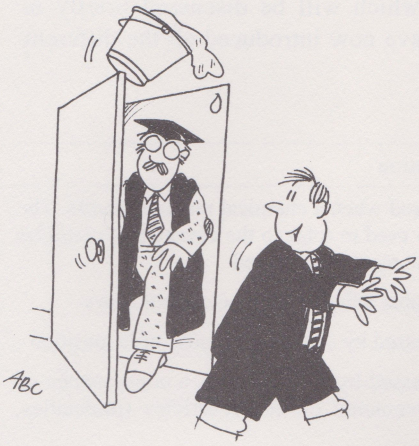
Experiment 6 Fix together two or three rubber bands to form a chain. Fix one end of the chain to the bag of coins. With a drawing pin, fix the other end to a secure wooden surface—e.g. a stout bread board. Arrange the bag alongside the drawing pin as shown in Figure 7. Push the bag over the edge and observe what happens. Take care that the 'drop' is sufficiently high for the bag not to reach the floor. If your rubber bands are very thick or very thin you may need to adjust the mass of the bag—by adding or subtracting coins. Note what you see.

Experiment 7 Obtain a reasonably powerful torch and switch it on. As an alternative, switch on the headlights of a car. What do you see? What do you feel with the back of your hand held a centimetre or so in front of the lens. Carefully touch the glass of the lamp when it has been on a few minutes. What do you notice?

TABLE 2 Types of energy in Experiments 4 to 7.

	Name of energy types involved. (Underline any new type not introduced in earlier Sections).
Experiment 4	*chemical energy, heat (internal energy), heat (radiant), sound, and light energy*
Experiment 5	
Experiment 6	
Experiment 7	

In Experiment 4, the chemical energy of the match—in both the wood of the matchstick and the compounds in the match head—is liberated by the chemical reactions involved in burning. Most of it appears as heat; the air round the match is heated and rises up from the flame in the saucer. The saucer itself also heats up. There is also some radiant heat. A small amount of the chemical energy of the match appears as **light energy**. As noted earlier, both radiant heat and light of all colours are part of the electromagnetic spectrum and all contain energy. As you haven't met light energy before, this is underlined in Table 2.



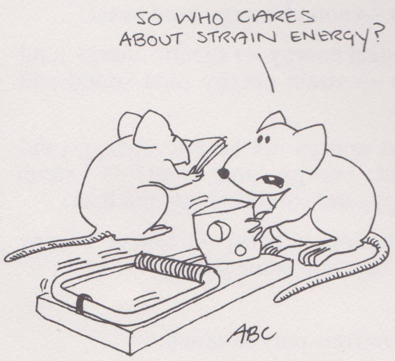
A BUCKET HAS GRAVITATIONAL ENERGY TOO!

Experiment 5 introduces the idea of **gravitational energy**[1]. This is the energy that an object possess as a consequence of its *position*. The idea that an object 'perched up high' has the potential to do a lot of work, whether for good or bad in human terms, is fairly commonplace. A mass of rock and ice held in an unstable way on a mountain has the potential to become the roaring mass of ice and snow that we call an avalanche; gravitational energy has been converted to kinetic energy with a vengeance! Similarly, the potential energy of a mass of water held in a dam can, if allowed to flow down pipes into a power station, be transformed into kinetic energy and then—within the turbines of the generators—into electrical energy. In this experiment, the kinetic energy of the falling bag becomes heat energy and sound energy as it strikes the floor. Although you heard the sound in your experiment, you will have to take it on trust that sensitive enough thermometers would detect a small increase in temperature in the floor where the bag landed. Your Table 2 entry for Experiment 5 should have been:

> gravitational energy, kinetic energy, heat and sound.

In Experiment 6, the gravitational potential energy of the bag is transformed as it falls into some kinetic energy and some **strain energy** in the stretched rubber of the elastic bands. Eventually, when the bag is stationary on the end of the stretched bands, almost all the gravitational energy that *was* in the bag on the table is now stored in the distorted rubber molecules within the rubber bands. Strain energy is very important in science and engineering. In geology, earthquakes are the consequence of the strain energy of rocks being suddenly released. A very small amount of heat energy will also have been produced as a consequence of the movement of the bag through the air. So, for Experiment 6, your Table 2 entry should have been:

> gravitational energy, kinetic energy, strain energy and (a very small amount of) heat energy.

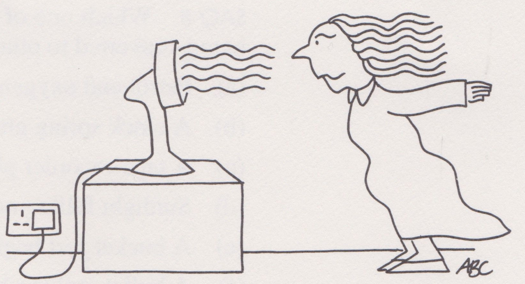


In Experiment 7 some of the chemical energy that is liberated by the complex chemical reactions inside the torch batteries or the car battery is converted to light energy. In that the glass of the torch or headlight also becomes warm or even hot, some of that liberated energy is also converted to heat (internal energy). The headlight beam will warm your hand at a considerable distance even on a frosty night—so radiant heat as well as visible light is produced.

The wire connecting the battery to the bulb carries another very important form of energy, namely **electrical energy**. This depends on the movement of electrons along the inside of the wires that conduct them. We will not discuss electrical energy further—except to note how important it is in human affairs. Electricity is the principal way in which energy is transferred from one place to another and, of course, a vast array of machines of many kinds are powered by electricity.

Your Table 2 entry for Experiment 7 should have been:

> chemical energy, electrical energy, heat energy (internal energy), radiant heat, and light.



ONE CONVERSION OF ELECTRICAL ENERGY

[1] This is sometimes referred to as gravitational *potential* energy or simply 'potential energy'.

With the exception of *nuclear energy*—which will be discussed briefly in Section 6—this Section and earlier ones have now introduced all the different forms of energy. Table 3 summarizes these.

TABLE 3 Different forms of energy.

Form of energy	Brief description
Chemical energy	energy released when a chemical reaction occurs. The term is often used to refer to the energy that *could* be released *if* the reaction occurred
Electrical energy	energy available when an electric current flows
Gravitational energy	energy possessed by an object because of its position
Heat energy (internal energy)	energy possessed by substances as a consequence of internal movements of their particles (molecules, atoms etc.)
Heat energy (radiant energy)	energy possessed by microwave and infrared radiation—part of the electromagnetic spectrum
Kinetic energy	energy possessed by an object because it is moving
Light energy	energy possessed by visible light—another part of the electromagnetic spectrum
Sound energy	energy possessed by sound. It is related to kinetic energy
Strain energy	energy possessed by an object because it is deformed in some way

Try SAQs 6 to 8 before moving on. You will need to draw on your general knowledge to answer some of these.

SAQ 6 Match the situations shown on the left with the energy conversions shown on the right. For example, if you think situation 1 is best described by the sequence of conversions in A, your answer will be '1A'.

1	Winding a clock	A	chemical energy $\rightarrow$ kinetic energy (and heat) $\rightarrow$ sound energy (and heat)
2	Bath water emptying	B	chemical energy $\rightarrow$ kinetic energy (and heat) $\rightarrow$ strain energy (and sound and heat)
3	Shaking a hand bell	C	strain energy $\rightarrow$ kinetic energy (and sound energy and heat) $\rightarrow$ strain energy (and sound energy and heat)
4	Arrow going from a drawn bow into a target	D	gravitational energy $\rightarrow$ kinetic energy (and heat and some sound)

SAQ 7 Think of one example from Industry or Transport in which:

(i) heat energy is converted via kinetic energy into electrical energy, and

(ii) electrical energy is directly converted into kinetic energy and heat.

SAQ 8 Which one of the different forms of energy listed in Table 3 is *initially* being converted to others in each of the following events?

(a) Petrol and oxygen exploding in the cylinders of a car.

(b) A clock spring gradually unwinding.

(c) A tape-recorder playing.

(d) Sunlight falling on a solar-powered calculator.

(e) A bucket *just* beginning to fall down a well.

(f) A bullet striking bone.

(g) An earthquake occurring in San Francisco, California.

5 UNITS OF ENERGY

Historically, the types of energy that were investigated first were those to do with movement and with heat. In 1763 an American adventurer called Benjamin Thompson—later made Count Rumford when he came to Europe—noticed that large amounts of heat were produced when metal was drilled out of iron tubes in the manufacture of cannons. Here was the first hint that kinetic energy could be converted to heat.

One of the most famous names associated with the development of ideas about energy is that of James Joule. By 1850, this Manchester brewer and part-time scientist had conducted a series of precise experiments—involving paddle wheels rotating in vessels of water—showing that there was a precise quantitative relationship between 'how much mechanical work you did' and 'how much heat was produced'; see the Box overleaf.

The SI unit of energy, mentioned early on in this Module, is named after Joule. Thus one speaks of 100 joules or 100 J—by convention, a small 'j' for the full name and capital 'J' for the abbreviated unit. But what *is* a joule? Is it a big unit or a little one? What, in everyday terms, do you feel like if you do 100 J of work? In fact, you have already met enough examples to know that one joule isn't much in human terms. You would do three or four joules of work opening a tin of cat food; you would do 100 joules of work putting your briefcase on the luggage rack in the train. As was noted earlier, you may have to expend 3 000 J to 6 000 J to push-start a vehicle.

To get a wider picture still, look at Table 4, page 17. This shows, very approximately, how much energy is involved in a range of events—some very routine, like the heartbeat, others rare, such as an exploding star, or even unique, such as the explosion of the Hiroshima bomb. Look at the table and try to get a 'feel' for the sizes of one joule (1 J), one kilojoule (1 kJ or 10^3 J) and one megajoule (10^6 J).

One other unit of energy is still in common use by nutritionists, dieticians and all who are weight-conscious. The unit is the **calorie**—and the countries of the well-fed West are all nations of calorie-watchers and calorie-counters. Look at the Box to see how calories and joules are related.

THE RELATIONSHIP BETWEEN CALORIES AND JOULES.

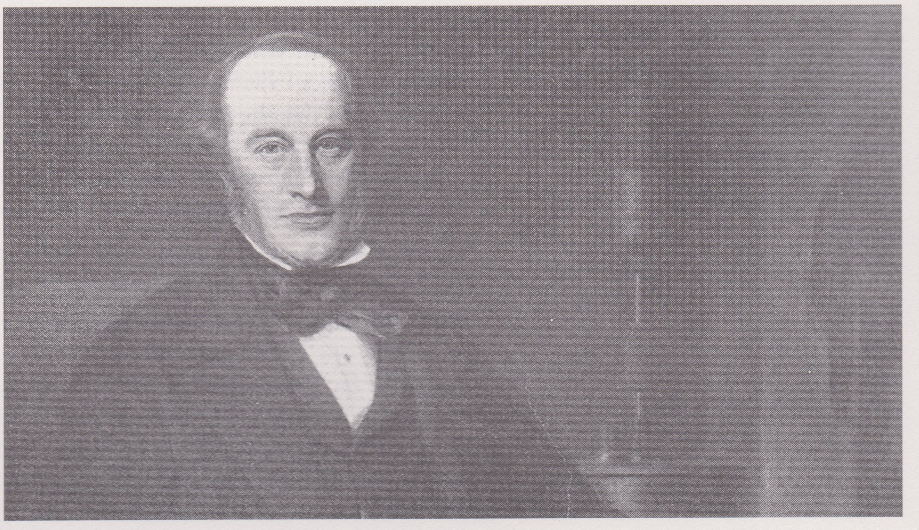
The calorie was originally defined as a unit of heat energy. It is the amount of heat needed to raise the temperature of 1 gram of water by 1 °C. Later, as joules came to be used, the 'conversion factor' between calories and joules became important. There are 4.185 joules per calorie; 4.2 joules per calorie is the approximate figure that many people use.

Both the joule and the calorie are rather small units in terms of human diet so it is not surprising that 'kilojoule, kJ' and 'kilocalorie, kcal' are widely used. A normal diet often provides around 2 500 kilocalories per day. Someone struggling to lose weight on a crash diet (with its associated health risks) might be eating 1 000 kilocalories per day or less. In fact, most non-scientists omit the 'kilo' prefix when talking about diets so you will hear someone say: 'Oh, I'm on a diet with only 800 Calories a day.' The capital 'C' is important: one Calorie is 1 000 calories. Some food manufacturers and many food writers are careless about the big 'C' versus the small 'c'. Fortunately, legislation about labelling foods is increasing clarity and correctness. If you fetch a carton of yoghurt from the fridge, you may well find the label says something like: '100 grams provide 42 kcal/176 kJ of energy …'.

In summary, 4.2 joules ≈ 1 calorie, and 4.2 kilojoules ≈ 1 kilocalorie. (The symbol ≈ means 'approximately equal to'.)
1 000 calories = 1 kilocalorie = 1 Calorie

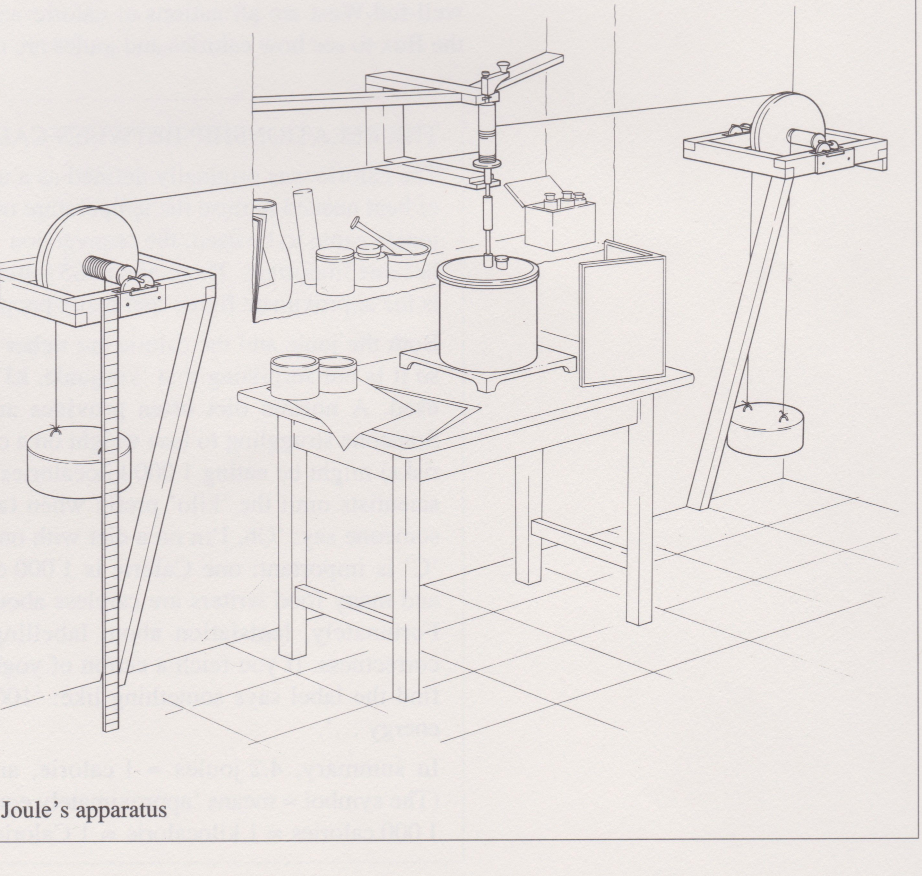
JAMES PRESCOTT JOULE

James Joule lived and worked in a time of great scientific activity in Britain and continental Europe. Like many scientists of his time he was well-off and pursued science as a hobby. In Manchester, where he was a brewer, there is some evidence that his name was pronounced 'jowl' as in 'owl with a J'! However, by custom and convention the unit named after him is always pronounced as '*jool*'.



James Joule 1818–89

His particular merit as a scientist lay in his ingenious and very accurate experimental work. The meticulously designed apparatus shown below permitted Joule to convert a known amount of gravitational energy via kinetic energy into the internal energy (heat) of the water in which a paddle wheel turned. By using this apparatus, the precise quantitative relationship between the energy of mechanical work and the energy of heat was revealed.



Joule's apparatus

International science nowadays avoids use of the calorie, the joule being the SI unit. As many food manufacturers often mark the 'energy value' of foods in calories, you may still be interested to know about this rather out-of-date unit. If you are used to thinking in terms of calories, then understanding this relationship will help you get a feel for joules. *But*, it is important to note that scientists work exclusively in joules.

Table 4 should give you a good feel for what sort of an amount of energy one joule is. And, as you now know, it is rather a small amount—two heartbeats' worth or opening a very dainty drawer. What has not been discussed at all is the *precise definition of the joule itself.* We do have one for the obsolete calorie—given in the Box—but we do not yet have a crisp, exact definition for a joule. So, what *is* a joule?

There is, of course, an exact definition—but it is one that depends on science that you will not meet until the *Foundation Course*. For now, while accepting that there *is* a proper scientific definition, simply think of a joule in terms of a 'quantity of energy that does something small'. You have many examples in Table 4—and, if you want a feel for just one joule, it is approximately the energy needed to raise one small orange from the floor to your kitchen work top.

SAQs 9 to 11 which follow are intended to familiarize you with the ideas of energy in Table 4. They also provide you with some revision work on calculating and on the use of scientific notation.

TABLE 4 Examples of energy quantities.

Item	Event	Energy/J
1	An electrical signal produced by a single nerve cell	10^{-10}
2	A beat of a fly's wings	10^{-6}
3	Work done by a single beat of the human heart	0.5
4	Opening a medium-sized drawer	1–5
5	Lifting a housebrick from floor to shoulder height	50
6	Walking upstairs	1 500
7	Energy transferred to floor when a 50 kilogram sack of cement drops 6 metres	3 000
8	Energy transferred to the body when a 50 gram bullet is stopped by bone	3 000
9	Energy needed to stop a car travelling at 70 mph	500 000
10	Energy in one person's food for a day	10 000 000
11	Energy in one litre of petrol	35 000 000
12	Kinetic energy of a large subsonic aircraft in flight	10^9
13	Energy of the Hiroshima atomic bomb	10^{13}
14	Annual energy output of a large power station	10^{16}
15	Energy of a very severe earthquake	10^{17}
16	Energy escaping from the interior of the Earth each year	10^{21}
17	Energy received by Earth from the Sun each year	5×10^{24}
18	Rotational kinetic energy of the Earth	10^{29}
19	Energy released in the explosion of a star	10^{44}

NOTE (i) Some energy values have been rounded to the nearest power; (ii) Items 13, 16, 17 and 19 involve nuclear power. This is discussed briefly in the Box on p. 21. (iii) Items 5 to 11 remind you that scientists don't always use scientific notation!

SAQ 9

(a) Write the energy values shown in items 1 and 12 in the table without using powers of ten. (*Hint*: In case you have forgotten, $10^2 = 100$ and $10^{-2} = 0.01$.)

(b) Write items 10 and 11 using powers of ten.

(c) How many beats of a fly's wing would take the same amount of energy as one beat of the human heart?

SAQ 10 Given that 1 calorie equals 4.2 joules, how many Calories are in the day's food referred to in item 10 of the table? Give your answer to two significant figures.

SAQ 11 The energy content of food is measured experimentally by burning it in a piece of apparatus called a 'bomb calorimeter'. In a particular type of bomb calorimeter, all the heat released during burning is 'caught' by the calorimeter and used to heat up 1 000 g of water. 1 gram of chocolate cake was completely burnt. As a result, the temperature of the water rose by 1.3 °C. What is the energy content in kJ of a 100 g cake? Take 1 calorie to be equal to 4.2 J. Give your answer to 3 significant figures.

Guidance note: This kind of calculation can cause difficulty as there are a lot of little steps that have to be put together in the right order. No step on its own is particularly difficult. You need to say to yourself 'What am I told?' and 'What do I have to find out?' You have to find out the kJ (kilojoules, not joules, not calories) in 100 grams (not 1 gram) of cake. You know that burning 1 gram heats 1 000 g water by 1.3 °C. You know what the definition of a calorie is. You should now be able to make a start on the SAQ.

6 THE LAW OF CONSERVATION OF ENERGY

The **Law of Conservation of Energy** is one of the most important and fundamental Laws of science. It underlies all the energy conversions that we have discussed—indeed, all the energy conversions that occur anywhere.

Think of the lament 'Well, the money must have gone somewhere!' If one has drawn £100 from a bank, given that the money has not been burnt, it must be somewhere—possibly split up between shops, petrol station, children's pockets or even having rolled down the drain. So it is with energy.

> The Law of Conservation of Energy states that energy cannot be created or destroyed. It can only be converted from one form to another.

Most probably, this idea will not come as any great surprise to you. Somehow, without ever being explicitly stated, every example of energy conversion so far discussed—theoretical or in an experiment—has contained the underlying notion that 'the energy goes somewhere'. What is now necessary is to put some figures into the diagrams of energy flow and see that the 'joules add up'. Let's explore one last example of an energy flow diagram, and then treat it quantitatively.

In the past you may possibly have played with the kind of toy pictured in Figure 8. It is a steam engine and, in principle, is a stationary version of the kind of engine that was used on the rail system until the 1960s. You probably know something about these if only from children's books and films—they are hot, noisy and they move.

There is no need to spend long on the energy conversions involved: you have done enough already! Figure 9 shows a partly completed energy conversion diagram. Now, imagine what the moving machine would be like. Apply what you learned in earlier Sections, together with this imaginary picture, and *complete the energy flow diagram in Figure 9 by adding whatever arrows you think are appropriate.*

When you have done that, take a look at Figure 10 on the next page. As you will notice, numbers have also been added to show the fate of the 30 kJ of energy released for each gram of alcohol that has been burned. This 30 kJ is equivalent to the '£100 drawn from the bank' in the money analogy. Where does it go?

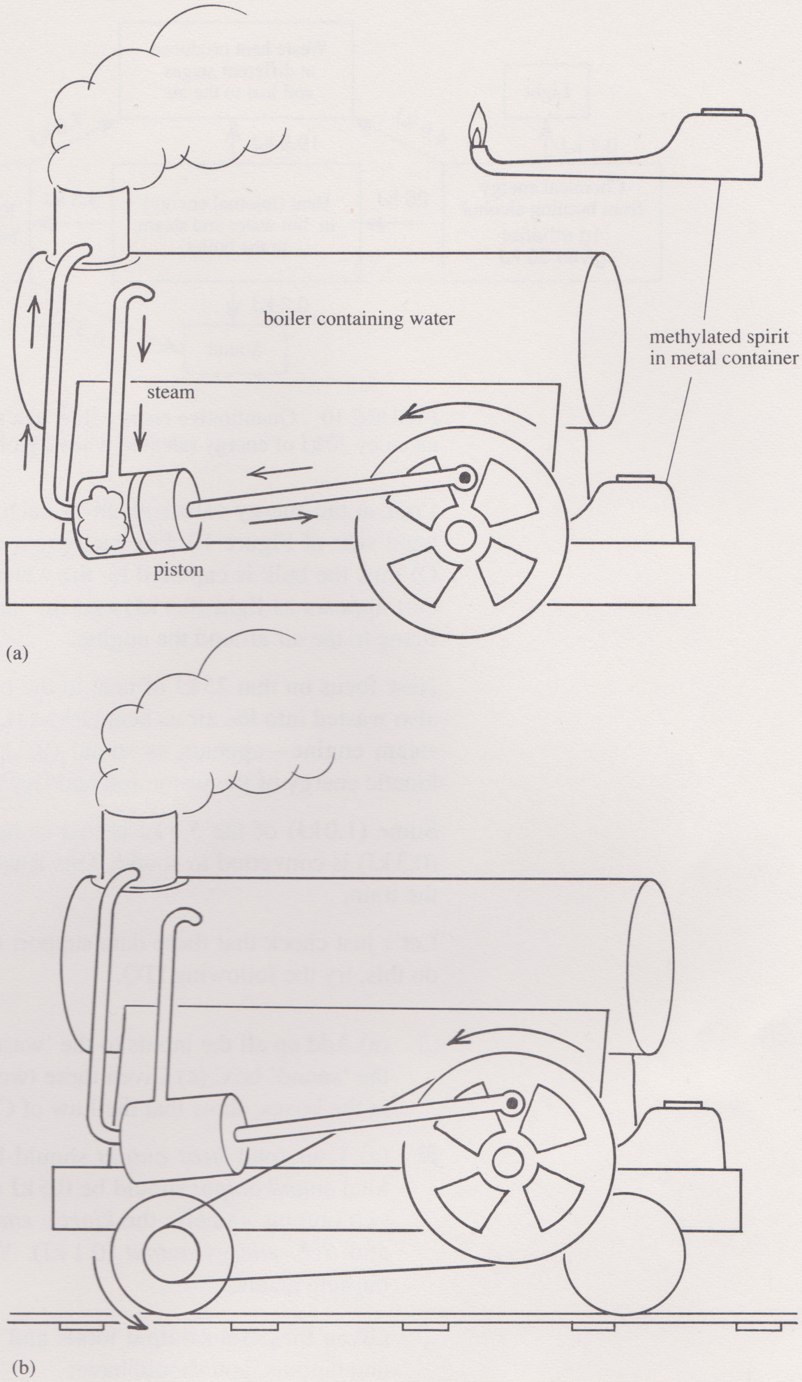


FIGURE 8 (a) A toy steam engine. The lighted burner containing methylated spirit—an impure form of alcohol—is put underneath the boiler of the steam engine. The water boils, steam is produced and the wheels turn. (b) The engine can be mounted on track wheels to make a simple train.

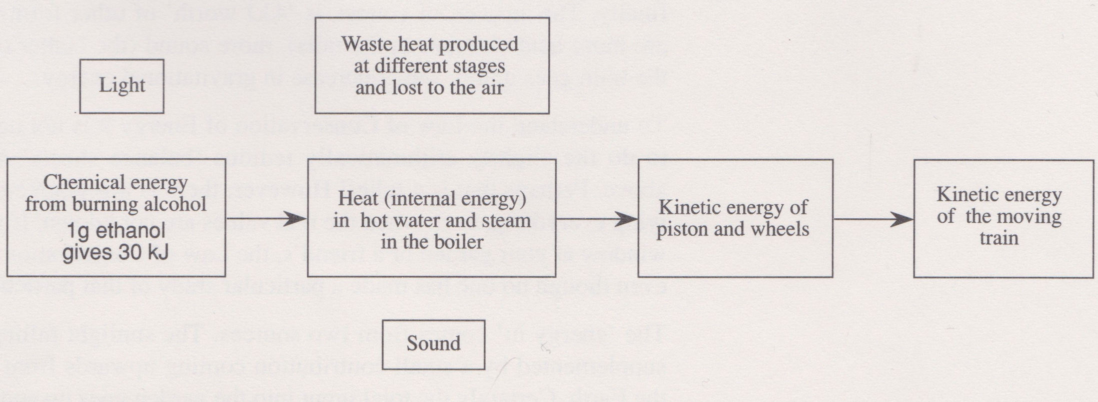


FIGURE 9 Energy conversions in a steam train.

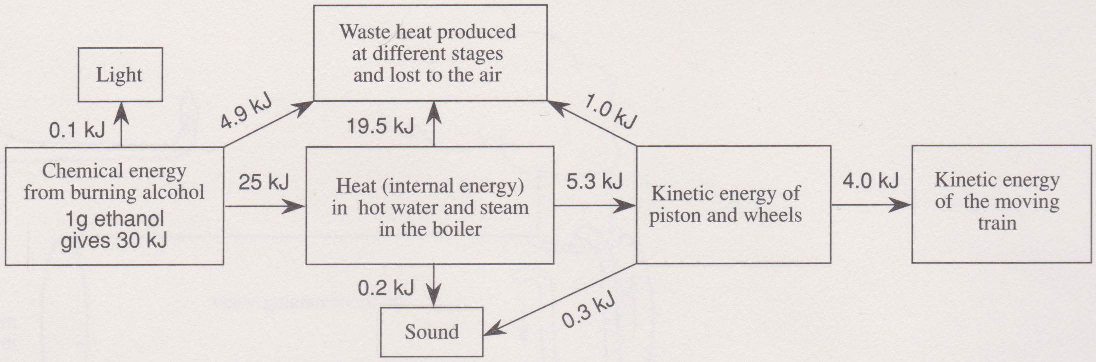


FIGURE 10 Quantitative energy flow in a toy steam train. The numbers show the route taken by 30 kJ of energy released when 1 g of alcohol is burnt.

Look at the energy values given by each arrow and work your way from the left hand side of Figure 10. For each gram of alcohol 30 kJ of energy are released. Of this, the bulk is captured by the water and steam of the boiler (25 kJ). A tiny part appears as light (0.1 kJ) and the balance (4.9 kJ) is waste heat lost by the flame to the air around the engine.

Now focus on that 25 kJ of heat in the boiling water and steam. Much of this is also wasted into the air as heat (19.5 kJ). Some of it—think of all the hisses of a steam engine—appears as sound (0.2 kJ). Just 5.3 kJ are left to become the kinetic energy of the piston rod and flywheel in the engine.

Some (1.0 kJ) of the 5.3 kJ is lost as heat as a consequence of friction. Some (0.3 kJ) is converted to sound. This leaves just 4.0 kJ of kinetic energy to move the train.

Let’s just check that these data support the Law of Conservation of Energy. To do this, try the following ITQ.

□ (a) Add up all the inputs to the ‘waste heat’ box. (b) Add up all the inputs to the ‘sound’ box. (c) Given these two totals and the *appropriate* other values in the boxes, show that the Law of Conservation of Energy is obeyed.

■ (a) Your total *heat output* should be 25.4 kJ (4.9 + 19.5 + 1.0). (b) Your total *sound output* should be 0.5 kJ (0.2 + 0.3). (c) You also need the other two outputs namely: the *kinetic energy output* of the moving train (4.0 kJ) and *light energy output* (0.1 kJ). You also need the total input from the burning alcohol.

Given these four output totals and the overall input, and comparing input and outputs, you should have:

30 kJ input = (25.4 + 0.5 + 4.0 + 0.1) kJ output

As expected, energy *in* equals energy *out*: the Law is followed.

You may well ask where the 4.0 kJ of kinetic energy of the moving train goes to finally. The answer, of course, is ‘4 kJ worth’ of other forms of energy. These are more heat (friction in the rails), more sound (the clatter of the train) and, if the train goes uphill, some increase in gravitational energy.

To understand the Law of Conservation of Energy it is not necessary to be able to do the slightly arithmetically tedious ‘balance sheets’ of the type shown above. Perhaps that is a relief! However, there is this degree of precision underlying everything, even when the real values are not known. If you look out of the window at your garden or a friend’s, the Law of Conservation of Energy applies, even though no one has made a particular study of that particular garden.

The ‘energy in’ comes from two sources. The sunlight falling on the garden is supplemented by a small contribution coming upwards from the hot interior of the Earth. Certainly the total input into the garden goes up and down day by day,

summer and winter, day and night. But there *is* an average input figure. The average 'energy out' figure must equal the input figure. If it did not, the garden would get steadily hotter or steadily colder depending on which of input or output was the larger.

The same requirement for *balance* applies to the whole planet: *energy in* must equal *energy out*. Some of the data are (approximately) known for this 'global garden' and you can see them as items 16 and 17 in Table 4. Arriving each year from the Sun itself (in the form of radiant energy) is around 5×10^{24} J. Also, escaping from the interior of the Earth is an annual total of 10^{21} joules. If the Earth is not to become hotter, then precisely that amount of energy (5×10^{24} J + 10^{21}J) needs to leave the Earth by radiation into space.

As you may have noticed for yourself, the ideas developed above are leading us towards a discussion of the greenhouse effect and global warming. There is evidence that the amount of energy being lost into space is slowly decreasing as the planet becomes more and more insulated by the effect of increasing carbon dioxide. Why the CO_2 concentration is increasing and how this may affect global temperature are questions of major importance, and are taken up again in Module 12.

A final note about *nuclear energy* is necessary. The idea of 'making energy by nuclear reactions' is so well known and is such a topical and contentious issue that, if the Module did not mention it, you might well have been left wondering. The main points are summarized in the Box for interest only.

NUCLEAR ENERGY

There are two main ways in which energy can be obtained from nuclear reactions. These are nuclear fusion (meaning joining atomic nuclei together) and nuclear fission (meaning splitting atomic nuclei apart). In Modules 5/6, you learned that atoms are very small, 10^{-10} m in diameter, but their nuclei are a hundred thousand times smaller still!

As early as the 1930s, experiments showed that energy could be released either by joining nuclei together or by breaking them apart. Was this, finally, a failure of the Law of Conservation of Energy? Strictly speaking, yes. However, in both kinds of nuclear reaction—that is both fusion and fission—the mass at the end of the reaction is slightly less than the mass at the beginning. *As a consequence of this loss of mass, a large amount of energy is released.* Moreover, there is always precisely the same ratio between the amount of mass lost and the amount of energy released. Because of the strict equivalence of mass and energy, the Law of Conservation of Energy still holds provided we *either* enlarge the meaning of energy to include its mass equivalent *or* talk of the 'Law of Conservation of Mass-Energy'.

The transformation of mass to energy in this way is very important. In the nuclear fission that occurs in the uranium-containing power stations that are dotted all over Europe, nuclei of uranium atoms are split—*and the mass that is lost appears as large amounts of energy* from which electricity is generated. Technology has not yet succeeded in harnessing fusion reactions to generate electricity. Indeed, it is only in hydrogen bombs that fusion reactions occur to any extent on planet Earth. In the Sun, however, fusion reactions are the crucial process. As a consequence of these reactions the Sun loses about 4 million tonnes of mass every second, with the consequent production of a vast amount of energy.

You can, as far as *Into Science* is concerned, leave any further consideration of nuclear energy. You simply need to be aware that there *is* a source of energy—an *input* in the sense of an energy flow diagram—that has its origin in mass and not in any of the other forms that you are now familiar with. Appreciating this is important because it answers the fundamental question 'where does all the energy that we see flowing from one form to another come from in the first

place?' If we ignore the amounts that flow out from the hot interior of the Earth, and ignore the amounts that are released by burning fossil fuels, the source that is left—by far the largest source[1]—is the radiant energy that we receive from the Sun. And all of that comes from nuclear fusion.

SAQ 12 relates to the Law of Conservation of Energy. Incidentally, it makes use of the letters X and Y to represent quantities of energy. Section 7 looks further into the use of letters in the mathematics that one uses in studying science.

SAQ 12 Suppose you spend an entire day lifting bricks from the floor to a surface one metre above the floor. You do this steadily so you do not have to stop. Suppose, too, that the energy value of the food respired in the body during that day was was X kJ ('X' is used because it avoids having to invent a real number). Suppose, finally, that you could calculate the gravitational energy stored in all the bricks you have lifted and found that it was Y kJ (again, 'Y' is used to represent the actual number). Imagine yourself doing this. Do you think X and Y would be equal? Bring the Law of Conservation of Energy into your explanation.

7 MATHS USING LETTERS: AN INTRODUCTION TO ALGEBRA

This Section, the last but one of the Module, introduces the use of symbols—almost always letters—as a means of representing and doing things with scientific ideas. This branch of mathematics is called **algebra** (pronounced 'aljebra' with the 'j' as in 'jug'). The word was originally an Arabic one and has been in use in English for more than 400 years as the name for the kind of maths-with-letters that we are about to explore.

7.1 EQUATIONS IN ALGEBRA: A WAY OF REPRESENTING IDEAS

Algebra is above all a marvellous way of being very general and absolutely precise at the same time. By using it, you can be quantitative without actually knowing the numbers involved. Sometimes it is used in everyday speech when people are trying to make a point: 'Look, suppose I had £X and … '. The speaker wants to be precise but doesn't have an exact value for 'X' in mind. You have met this idea once already in this Module in SAQ 12.

In algebra the letter chosen to represent something is often the first letter of the quantity in question—for example M for mass, t for time, l for length and so on. Where you want to use the same letter to represent slightly different meanings, a *subscript* number is frequently used, for example T_1 for 'initial temperature' and T_2 for 'final temperature'. You would say these as 'tee one' and 'tee two'.

Here, the actual values of T_1 and T_2 do not matter. The key point is that if these two temperatures are measurements in a cooling curve, we can say that the decrease in temperature is $T_1 - T_2$. The word 'is' is mathematically the same as the equals sign. Thus we have made for ourselves the equation:

$$\text{decrease in temperature} = T_1 - T_2$$

You may perhaps decide that this is still too wordy: it would be more concise to have another symbol to represent 'decrease in temperature'. How about 'D'?

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[1] Compare items 16 and 17 in Table 4. You can see that the Sun contributes vastly more energy than is contributed by heat from the Earth's interior.

If you are organizing the algebra, you are entitled[1] to choose anything you like, so you could have chosen any letter you liked. Let's keep to 'D' for now. The equation can now be written:

$$D = T_1 - T_2$$

The algebra is simply *shorter* and, even more important, equations in algebra can be *manipulated*—as we shall now see. By the way, 'equations in algebra' are called **algebraic equations** (pronounced 'al-je-bray-ic' equations; as before, the 'j' is as in 'jug').

SAQ 13 provides practice in writing ideas in algebraic form.

SAQ 13 The *Manufacturer's price* for a new car is less than the *Retail price* at the garage. That is because (i) *Tax* has to be added to the the manufacturer's price; (ii) there are certain incidental *Costs,* such as delivery and number plates; and (iii) the garage makes a *Profit.* Using letters M, R, T, C and P to represent the italicized items, write down an equation connecting retail price with manufacturer's price, tax, costs and profit. (*Hint*: Retail price is to be the subject of the equation, so it should begin $R = \dots$.)

7.2 REARRANGING ALGEBRAIC EQUATIONS

Let us explore the idea of 'manipulation' introduced recently. The word 'manipulating' implies that something is being adjusted so that it appears in a particular way. So it is in algebra: we can adjust equations to put them in the form required. The proper word to describe this adjusting process is 'rearranging', and the rules for rearranging equations are very precise. How is it done?

The answer to SAQ 13 was:

$$R = M + T + C + P$$

If you were the garage owner, you might be interested in rearranging this equation so that your profit (P) was the subject of the equation. The result of such manipulation is the equation:

$$P = R - M - T - C$$

You do not need any real algebraic skill to see that this result is common sense: your profit is the price you sold it for minus the price you paid the manufacturer minus the amount that had to be paid to the tax authorities minus the incidental costs in putting number plates on and getting it delivered to your garage.

Unfortunately, you cannot rely on knowing the 'underlying meaning' of an equation in order to manipulate it. To do so would mean that you always needed to know the answer before you did the sum! To avoid this you need to be aware of the 'rules' for rearranging equations—and be able to use them. The rest of Section 7.2 looks into this.

The most important thing about an equation in algebra is its equals sign. The 'bit on the left' *equals* 'the bit on the right' and, if it is to remain an equation, must continue to do so. From this, you can probably see that if we 'do something' to the left-hand side and then 'do exactly the same thing' to the right-hand side, we still have an equation.

Picture some old-fashioned kitchen scales that are in balance because there is a kilogram of sugar on the left and a kilogram of sugar on the right. Suppose you

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[1] Like so much in life, though free one is also bound by convention. It is usual to use M for mass, T for temperature, t for time, d for distance, v for velocity and so on. In many branches of science and in maths itself, convention often becomes a rule. Physicists always use the Greek letter λ (pronounced lambda) for the wavelength of light and ρ (pronounced 'rho') for the density of substances. Mathematicians are equally organized: π ('pi') is used in working out things about circles—as you'll see in the next Module—and they often use θ ('theta') to represent angles.

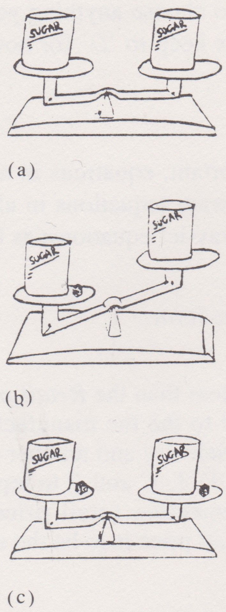

FIGURE 11 (a) Equal and balanced without the cubes; (b) unequal and unbalanced with only one sugar cube; (c) equal and balanced with a cube on each side.

add a sugar cube to the left-hand pan. What must you do to keep the scales balanced? Add an identical sugar cube to the right-hand pan, of course. Look at Figure 11 for a pictorial view.

The same idea applies to algebraic equations and this gives us the rule:

(1) Any quantity can be added to the left-hand side of an equation as long as the same quantity is added to the right-hand side.

The same imaginary situation can be used as an analogy for subtraction. This time imagine that a tablespoonful of sugar is removed from each pan. This gives:

(2) Any quantity can be subtracted from the left-hand side of an equation as long as the same quantity is subtracted from the right-hand side.

When it comes to multiplying and dividing, the sugar model continues to be helpful. If you multiply the left-hand side by three (three one-kilogram bags of sugar) you need to multiply the right-hand side by three—that is, have three bags, each of 1 kg, on this side too—to keep the scales balanced. In like manner you can see that as long as each side is divided by the same amount, both sides of the equation remain equal. This gives the rules:

(3) The left-hand side can be multiplied by any amount as long as the same is done to the right-hand side.

(4) The left-hand side can be divided by any amount as long as the right-hand side is divided by the same amount.

All of these rules can be summed up in one rule:

> Whatever you do mathematically to one side of an equation, you must also do to the other side.

As long as you do this, your equation remains an equation.

What has this to do with rearrangement? Everything! The rule in the box above enables you to manipulate equations without error—and without knowing the answer first. Consider the equations to do with the car showroom. We originally had the equation:

$$R = M + T + C + P$$

To calculate profit, we want to rearrange the equation so that P is the subject. At present P is on the right-hand side of the equation, together with several other letters. If we want P as the subject, we want it to be entirely alone and on the left-hand side. We can achieve this by subtracting M and T and C from the right-hand side. By the rule of 'doing the same to each side' we must also subtract M and T and C from the left-hand side. This gives us:

$$R - M - T - C = M + T + C + P - M - T - C$$

Concentrate on the right hand side. Look at the 'C's. There is a $+C$ and a $-C$; these cancel[1] each other out to give zero. There is a $+T$ and $-T$; again these cancel each other out. And finally there is an M (+ is implied) and $-M$ which again give zero. Writing this out we have:

$$R - M - T - C = \cancel{M} + \cancel{T} + \cancel{C} + P - \cancel{M} - \cancel{T} - \cancel{C}$$

and we finish up with:

$$R - M - T - C = P$$

It is usual to put the *subject* of any equation on the left, so we simply rewrite it as:

$$P = R - M - T - C$$

---

1 When you cancel things in arithmetic or algebra, you cross them through with a diagonal line—showing that the item you have cancelled no longer exists in the equation.

This is the same answer as the one obtained by the 'common sense' approach on page 23.

Finally, we shall look at an example of a rearrangement involving multiplication and division. Let us take a straightforward example. Density, you remember from Module 3, is mass divided by volume. That is:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

To say that liquid metal mercury has a density of 13.6 g cm^{-3} simply means that one cubic centimetre of it has a mass of 13.6 grams. In general algebraic terms:

$$\rho = \frac{M}{V} \text{ where } \rho \text{ (rho) is density, } M \text{ is mass and } V \text{ is volume.}$$

Let's check the sense of this by putting some numbers into the equation. If you had 27.2 grams of mercury with a volume of 2 cm^3, then the equation would give $27.2 \div 2$. This is the density of 13.6 g cm^{-3} that we are expecting.

Suppose however, you want to rearrange this equation so that volume is the subject. How can $\rho = M/V$ be made into an equation that begins $V = \ldots$? This is achieved using a number of steps which, when written out in full, look very long-winded. However, with practice, the manipulation becomes very quick and routine—in short, easy! So how is this manipulation done? Before we attempt it, look now at the Box on page 26; this deals with 'getting rid of fractions in algebra'. Do this now.

Now that you have learned about 'getting rid of fractions in equations', let's return to the task of rearranging the equation about density. The task, you will recall, is to rearrange $\rho = M/V$ to make V the subject of the equation. That is, we want $V = \ldots$

The method depends on ideas from the Box that you have just read. The first step is to 'get rid of the fraction'. We do this by multiplying both sides by the denominator V. So we get

$$\rho \times V = \frac{M}{V} \times V$$

Now we cancel out the 'vees' on the right hand side:

$$\rho \times V = \frac{M}{\cancel{V}} \times \cancel{V}$$

and we get:

$$\rho \times V = M$$

The next stage is to divide both sides by ρ. This will, after some cancelling, leave us with V isolated on the left of the equation as $V = \ldots$

So,

$$\frac{\cancel{\rho} \times V}{\cancel{\rho}} = \frac{M}{\rho}$$

which gives

$$V = \frac{M}{\rho}$$

We're there! With practice, the method becomes very familiar and—in the end—quite easy. You may well find yourself doing many of the intermediate cancelling steps in your head—in which case the whole thing becomes much shorter.

GETTING RID OF FRACTIONS IN ALGEBRA

When rearranging equations which have fractions in them, the first step—almost always—is that of 'getting rid of the fraction'. The 'rule' is simple: you just multiply both sides of the equation by 'the thing on the bottom of the fraction'. If this sounds incomprehensible, this example using numbers may help.

If the mass of a book is $\frac{1}{3}$ kg we can write the equation:

$$M = \frac{1}{3}$$

To get rid of the fraction 1/3 we *multiply both sides* by 3 (the thing on the bottom of the fraction). Note that when we 'multiply both sides by 3' we are simply applying the rule of 'doing the same thing to both sides of the equation' that was introduced earlier. So, we have:

$$3 \times M = 3 \times \frac{1}{3}$$

Look at the right hand side of this equation first:

What we are about to do now is another kind of cancelling. If you multiply something by three and then divide the result by three, you are clearly back where you started. We might as well not have done either operation. This can be shown in 'three × one third' by writing it out in full and then crossing out, with a single diagonal line, both 3s. This is called *cancelling* out the threes.

Thus, $\cancel{3} \times \frac{1}{\cancel{3}} = 1$ So the right hand side equals 1.

Now look at the left hand side of the equation:

Remembering from Module 1 that the × sign, as in $3 \times M$ is often omitted in mathematics, the left hand side of the equation is simply $3M$.

Now put the left hand side equal to the right hand side:

$$3M = 1$$

The 'getting rid of fractions rule' can be summed up:

Multiply both sides by the denominator

The **denominator** is the thing on the bottom of the fraction, and the thing on the top is called the **numerator**.

Just to make sure you can do it, look at the following three increasingly complicated examples. The task is simply 'get rid of the fraction in the equation'.

(1) $q = \frac{4}{7}$

The denominator is 7, so multiply both sides by 7

$$7q = \frac{4}{7} \times 7$$

After doing the appropriate cancelling, we get $7q = 4$

(2) $a + b = \frac{3}{4}$

The denominator is 4, so multiply *all of* both sides by 4. After doing the appropriate cancelling, we get $4(a + b) = 3$

(3) $a + b = \frac{x}{y}$

The denominator is y, so multiply all of both sides by y. After doing the appropriate cancelling, we get $y(a + b) = x$.

Now try something looking more complicated. Recall the Experiment in Section 3.1. The rate of cooling was the decrease in temperature divided by the time it took for that decrease to occur. We already have an expression in algebraic terms for the decrease in temperature. It is:

$$T_1 - T_2$$

If the time when we measure T_1 is t_1 and if the time when we measure T_2 is t_2, then the time taken for the cooling to occur can readily be worked out.

□ What is the time taken for the water to cool from T_1 to T_2?

■ $t_2 - t_1$ Note that $t_1 - t_2$ is incorrect! The smaller value (t_1) has to be subtracted from the larger one (t_2).

You now have an algebraic expression for the temperature decrease ($T_1 - T_2$) and also for the period of time ($t_2 - t_1$). You probably can now write down an equation for the rate of cooling over this period. Rate, remember, is decrease in temperature divided by time taken. If the letter R is chosen to represent the rate of cooling:

□ Write an equation for R using $T_1 - T_2$ and $t_2 - t_1$

■ The equation is $R = \dfrac{T_1 - T_2}{t_2 - t_1}$

To get this numerically correct—recall your experiment—it is necessary to do the two subtractions before the division.

□ Why is it not necessary to put *brackets* round $T_1 - T_2$ and $t_2 - t_1$?

■ The answer is that the horizontal line of a fraction (algebraic or otherwise) has the force of a bracket: you always fully work out the numerator and the denominator *before* you do the division. However, if you *wish* to put brackets around each of ($T_1 - T_2$) and ($t_2 - t_1$), you can! To do so is not wrong.

Once you *know* how to rearrange equations and have practised it, manipulations of this type become quite easy. At the start, if you are new to it, it can be quite hard. However, there is a quite simple technique that you can use whenever you feel 'a bit stuck'—this is to put simple *numbers* into an equation to replace one or more letters.

Here is an example. Suppose you are asked to rearrange $x = y^2$ so that y is the subject of the equation. In fact, you take the square root of each side so that $\sqrt{x} = y$. Then putting the subject on the left, you get the answer $y = \sqrt{x}$. If that is a puzzle, try numbers. For example, if $y^2 = 16$, fairly 'obviously' $y = 4$. You have intuitively taken the square root of each side. After doing that, the 'all letters task' of $x = y^2$ seems much easier.

Try another. Given that $n = 3m + 2$, make m the subject of the equation. The rules of rearrangement give the answer:

$$m = \frac{n-2}{3}$$

Do you *believe* it? Try $3m + 2 = 11$. It is fairly easy to see that $3m = 11 - 2 = 9$. And if $3m = 9$, $m = 9 \div 3$, and so $m = 3$. But you also get the answer $m = 3$ if $n = 11$ is substituted for n in the rearranged equation:

$$m = \frac{n-2}{3} = \frac{11-2}{3} = \frac{9}{3} = 3$$

and this shows that the rearranged equation is correct! Try SAQs 14 and 15.

> When in difficulties in algebra, try putting simple numbers in place of letters to help work it out.

SAQ 14 Rearrange each of the following equations to make the bracketed letter the new subject.

(a) $A = B + C - D$ [D]

(b) $s = \frac{g}{f}$ [g]

(c) $F = ma$ [a]

(d) $W + X = Y + Z$ [Y]

(e) $x = y^2 + 4$ [y]

(f) $y = \sqrt{x + 2}$ [x]

SAQ 15 The rate of cooling (R) is connected to the temperature decrease $(T_1 - T_2)$ in the period of time $(t_2 - t_1)$ by the equation :

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

(a) Rearrange this with $T_1 - T_2$ as the subject of the equation.

(b) Rearrange this with $t_2 - t_1$ as the subject of the equation.

(c) Rearrange this with T_1 as the subject of the equation.

7.3 APPLICATION OF ALGEBRA

Let us return to the power of algebra as a means of expressing general relationships. Can algebra be of assistance in discussing the Law of Conservation of Energy? Consider Figure 10 once again. If we let the energy input from burning alcohol be A kJ, the amount of light energy produced be L kJ, the amount of sound energy be S kJ, the amount of heat energy be H kJ and the kinetic energy of the train be K kJ, we can write the relationship:

$$A = L + S + H + K$$

This is, you might argue, not very different from the equation we had about the toy train involving numbers (30 = 25.4 + 0.5 + 4.0 + 0.1). That is the whole point! Saying it in algebra is simply much more general.

Like any other equation in algebra, we can make different letters the subject of the equation. By applying what you learnt about rearrangement earlier you can easily make L and then S the subjects as follows:

$$L = A - S - H - K$$

$$S = A - L - H - K$$

Can you make K the subject of the equation? Try it. The answer is

$$K = A - L - S - H$$

In terms of what these letters represent, does this equation make sense? Try putting the meanings of the letters back in:

> kinetic energy of the train equals the energy released from the alcohol minus that wasted as light, minus that wasted as sound, minus that wasted as heat

That sounds very reasonable!

It is, of course, not only the science of this Module that can be helped by the application of algebra. In Module 3, *Looking at Buildings*, you met Pythagoras' theorem. Revising it briefly, you saw how the length of the two smaller sides of a right angled triangle are related to the longest side: the *hypotenuse*. Figure 12 shows a right angled triangle with sides that are 3 cm, 4 cm and 5 cm long.

Pythagoras' theorem says that the square of one shorter side added to the square of the other shorter side equals the square of the hypotenuse (longest side). In that $3^2 + 4^2 = 5^2$ ($9 + 16 = 25$), the theorem clearly works here. In fact it works for all right angled triangles, and the theorem can be expressed algebraically:

$a^2 + b^2 = c^2$ where a and b are the two shorter sides and c is the hypotenuse.

This equation can be rearranged as one wishes.

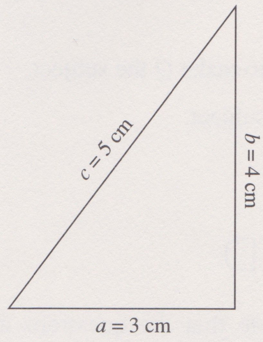

FIGURE 12 A right-angled triangle.

To make b the subject of the equation, it is first necessary to isolate b^2 on its own on one side of the equation. Clearly to get b^2 on its own, we must subtract a^2 from both sides.

Thus we get:

$$b^2 = c^2 - a^2$$

To get b *itself* the subject of the equation, it becomes necessary to take the square root of each side So we have:

$$\sqrt{b^2} = \sqrt{c^2 - a^2}$$

But the square root of b^2 is b (just as the square root of 4^2 is 4, that is $\sqrt{4^2} = 4$). So:

$$b = \sqrt{c^2 - a^2}$$

As noted in the answer to SAQ 14, the long line at the top of the 'tick' (square root sign) acts rather like a bracket and means everything under the line must be worked *out* before the square root is taken.

You will find that algebraic equations are common in science. They summarize in a few letters what may have taken years of experimentation to discover. Handling them is not hard provided that (a) you know the rules (b) you often ask yourself *what the meaning of the equation is* and do not just treat it as 'magic'. Finally, (c), you must practise.

As regards common sense, consider this example. Kinetic energy is related to the mass of the moving object (M) and its velocity (v) by the equation:

$$\text{kinetic energy} = \frac{1}{2}Mv^2$$

□ Would you expect a heavier object to have more kinetic energy? (Assume that all other variables are the same.)

■ Of course! Better to be hit by a ping-pong ball than a cannon ball. This common sense approach—that is, the practical science approach—is confirmed by the equation above for kinetic energy: if M is made twice as big, kinetic energy will be twice as big.

□ Would you expect a faster object to have more kinetic energy? (Assume that all other variables are the same.)

■ Of course! Slow moving cars are much less lethal than fast ones, a point emphasized in modern 'don't break the speed limit' propaganda. Once again, common sense helps. Actually, if the speed is doubled, kinetic energy increases by four times; if speed is trebled, kinetic energy increases by nine times. This is the consequence of the 'squared' bit of the equation.

Now practise! Try SAQs 16 and 17.

SAQ 16 Given the equation for kinetic energy in the previous paragraph, write down an equation that shows the velocity, v, of a cannon ball if it has a mass M and a kinetic energy of E.

SAQ 17

(a) The quantity of heat escaping from the interior of the planet Earth is Q joules and the surface area of the entire planet is $A\ \text{m}^2$. If the average flow of heat in joules per square metre is F, write down an equation that relates F to Q and A. Your equation should have F as its subject.

(b) Rearrange the equation you obtained in part (a) to make Q the subject.

(c) Similarly, rearrange the equation to make A the subject.

8 ENERGY CONCLUDED

You have had indications throughout this Module that the questions about energy occur in crucially important ways in all branches of science.

It is not only 'physics as physics' that is concerned with energy. Reference to 'joules', energy flow, internal energy, radiant energy, the Law of Energy Conservation and so on occur throughout science. For example, in SAQ 17 (and in item 16 of Table 4) 'heat escaping from the interior of the Earth' was rather casually mentioned. If you compare items 16 and 17 of Table 2 it looks as if 'heat from inside the Earth' is but a tiny fraction of the heat we get from the Sun. That is true: 5×10^{24} J is 5 000 times larger than 10^{21} J. But the significance of that 10^{21} J is enormous—and accounts for the very large temperature gradient as one moves towards the Earth's centre. How that energy is released and what effect it has on the materials from which the planet is made are questions of great importance to Earth scientists—as you will see in the *Foundation Course*.

The 5×10^{24} J of radiant energy that, thanks to nuclear fusion, reaches Earth from the Sun powers the whole of the living world. Photosynthesis—you met that briefly in Module 7—is the process by which plants capture some of that 5×10^{24} J and form glucose and oxygen ($C_6H_{12}O_6 + 6O_2$) from carbon dioxide and water ($6CO_2 + 6H_2O$). Respiration inside cells is the process by which some of that chemical energy is released (so that you can lift bricks, push-start cars, draw bows and other things). These processes are dealt with in parts of biology. So also is the *flow* of energy from plants to animals that eat plants, to carnivores and so on. These food-chains, as they are called, are part of ecology and the Law of Conservation of Energy is important in discussing and describing the food-chains that occur in nature.

9 OVERVIEW

SUMMARY

These are the concepts you have learned about in this Module:

- Energy is the capacity to do work.
- Energy exists in different forms that can be converted from one to another. These energy conversions can be represented in diagrams.
- Heat (as internal energy) and temperature can be described in terms of kinetic energy.
- Boiling and cooling can be explained in terms of kinetic energy.
- Joules and calories are both measures of energy: 4.2 joules = 1 calorie.
- The Law of Conservation of Energy always holds true.
- Algebraic equations are a means of representing scientific relationships.

SKILLS

Now that you have completed this Module, you should be able to:

- draw flow diagrams to represent energy conversions
- express relationships described to you in words in the form of algebraic equations
- rearrange algebraic equations to make different letters the subject of the equation
- check the reasonableness of rearranged equations by using scientific common sense
- use algebra and arithmetic to solve problems about scientific relationships.

APPENDIX 1: EXPLANATION OF TERMS USED

ALGEBRA A branch of mathematics in which numbers can be represented by letters.

ALGEBRAIC EQUATION Any equation that involves symbols instead of, or in addition to, numbers. The symbols are usually letters from the Roman or Greek alphabets (abc… or αβγ…). Equation is defined in Module 1.

CALORIE A non-SI unit of energy. One calorie is defined as the amount of heat energy needed to raise the temperature of 1 g of water by 1 °C. One calorie is about 4.2 joules. A kilocalorie (otherwise known as a Calorie—with a capital C) is 1 000 calories.

CHEMICAL ENERGY This is the energy released when a chemical reaction occurs. The term is often used to refer to the quantity of energy that *could* be released *if* the reaction occurred.

DENOMINATOR The bottom part of a fraction. Examples are 2 in 1/2 and m in $1/m$

ELECTRICAL ENERGY Energy available in electricity.

ELECTROMAGNETIC SPECTRUM The complete set of all wavelengths of electromagnetic radiation. Some well-known examples, in order of increasing wavelength, are X-rays, ultraviolet light, visible light, infrared light and microwaves.

ENERGY Energy exists in several forms, for example kinetic energy and gravitational energy. All forms have the capacity to do work.

FRICTION This is the mechanical rubbing together of surfaces. As a consequence of friction, kinetic energy is converted to heat energy.

GRAVITATIONAL ENERGY This is the energy possessed by a mass as a consequence of its position.

HEAT ENERGY There are two kinds of heat energy: internal energy and radiant heat. Internal energy is that possessed by substances and is a consequence of movement of particles in that substance. Radiant heat, as the name suggests, is radiation in part of the electromagnetic spectrum (especially infrared and microwaves).

INTERNAL ENERGY See 'heat energy'.

JOULE The SI unit of energy. A capital J is its abbreviation. One kilojoule (kJ) is 1 000 joules.

KINETIC ENERGY This is the energy possessed by a mass as a consequence of its movement.

LAW OF CONSERVATION OF ENERGY This states that energy can neither be created nor destroyed, but only converted from one form to another.

LIGHT ENERGY Energy possessed by light—the visible part of the electromagnetic spectrum.

NUMERATOR The top part of a fraction. Examples are 3 in 3/4 and x in $x/5$

RADIANT HEAT See 'heat energy'.

RATE This means how much something changes per unit time; e.g. the rate of increase of a population might be 10^6 people per year; 6 °C min^{-1} might be how fast your cup of tea cools immediately after it has been poured.

SOUND ENERGY Energy possessed by sound. It exists as a consequence of movement (compression, vibration, etc.) of the particles in the substance through which the sound passes. It is a form of kinetic energy.

STRAIN ENERGY This is energy possessed by a body as a consequence of some kind of 'distortion' imposed upon it. A spring or rubber band, for example, can possess strain energy.

WORK When work is done on a system, energy is given to it and some change in the system is detectable.

APPENDIX 2

COMPLETED VERSION OF FIGURE 2

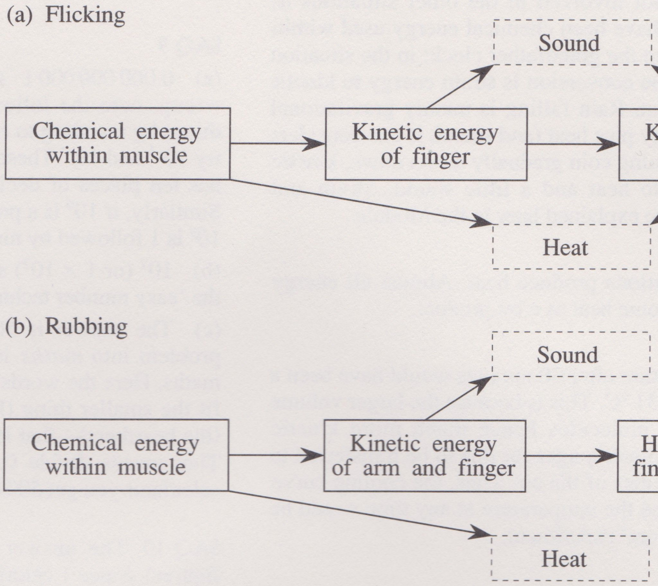

FIGURE 13 Complete energy conversion diagrams for Experiments 1 and 2.

SAQ ANSWERS AND COMMENTS

SAQ 1 (b) (c) and (f). Respectively, these are: the chemicals of wood reacting with oxygen; the chemicals inside the battery reacting to produce electricity; the stored food inside the seed being respired.

Chemical energy is not involved in the other situations *as described*. There will have been chemical energy used within the hand that wound up the grandfather clock: in the situation described, however, the conversion is strain energy to kinetic energy, sound and heat. Rain falling is mainly gravitational energy to kinetic energy plus heat (and sound, if one considers the impact). As a spinning coin gradually slows down, kinetic energy is converted to heat and a little sound. Strain and gravitational energy are explained later in the Module.

SAQ 2 All the situations produce heat. Almost all energy conversions produce some heat as a by-product.

SAQ 3 The temperature after 30 minutes would have been a good deal higher than 31 °C. This is because the larger volume contains many more molecules hence much more kinetic energy. It would take much longer for this to be transferred to the surrounding molecules of the air. Thus, the cooling curve would be shallower and the temperature at any time would be higher than in the 300 cm^3 experiment.

SAQ 4 Mary's kitchen must be very cold compared with the kitchen used by the second student. The rate at which kinetic energy was lost from her water was high, and this is reflected by the faster decrease in the temperature: 6 $°C\,min^{-1}$ compared with 4 $°C\,min^{-1}$, even though the water temperature was the same (70 °C) in both cases. Thus kinetic energy is lost more rapidly and, similarly, the temperature decreases at a greater rate.

SAQ 5 From Figure 5, the rate of cooling is about 1 $°C\,min^{-1}$ over the period stated. To work this out, you should have drawn vertical lines upwards, from 18 minutes and 28 minutes on the time axis, to meet the curve. Going horizontally from these two contact points to the temperature axis, our estimate of the temperature at 18 minutes was 42 °C and at 28 minutes was 32 °C. Thus over the 10 minute period the temperature fell by 10 °C. 10 °C divided by 10 minutes gives a rate of 1 $°C\,min^{-1}$.

SAQ 6 The matched pairs are: 1B, 2D, 3A and 4C. Note that some quantities produced will be very small. They are none the less real: when you place an apple on a table, a small amount of kinetic energy *will* heat the table a fraction of a degree at the point of contact. You should, however, make sure that you are aware of the *principal* route(s) along which most energy flows in any particular situation.

Note that when an arrow forces the fibres of the target apart to accommodate the buried arrow head, there is strain energy in the distorted molecules. This much is obvious from everyday experience if you reflect how much effort (= energy) is required to hammer a nail into wood.

SAQ 7

(i) Many different answers are possible. One example is coal burning in a coal-fired electricity generating power station.

(ii) One example is an electric train travelling along the rail track.

SAQ 8 Here, the question asks about the first type of energy in whichever sequence of energy conversions is occurring. The answers are: (a) chemical energy, (b) strain energy, (c) electrical energy, (d) light energy; radiant energy is an acceptable alternative, (e) gravitational energy; gravitational potential energy is acceptable, (f) kinetic energy, (g) strain energy.

SAQ 9

(a) 0.000 000 000 1 and 1 000 000 000 If you got these wrong, note the following. You can always work out hard things by resorting to easy ones first. So, if 10^{-10} is a problem, try 10^{-1} and 10^{-2} These are 0.1 and 0.01 respectively. So 10^{-10} has ten places of decimals (or nine noughts, if you prefer). Similarly, if 10^9 is a problem, try 10^2 You know this is 100, so 10^9 is 1 followed by nine noughts.

(b) 10^7 (or 1×10^7) and 3.5×10^7 If you had problems, use the 'easy number technique' to work out how to do it.

(c) The answer is 500 000 beats. Turning the *words* of a problem into *maths* is quite often harder than solving the maths. Here the words simply mean how many times can you fit the smaller thing (beat of the wing) into the bigger thing (the heartbeat)—that is, see how many lots of 10^{-6} fit into 0.5 That means divide 0.5 *by* 10^{-6} Working this out on your calculator you get 500 000 (5×10^5).

SAQ 10 The answer is 2 400 Calories (to two significant figures). Since 1 calorie (little 'c') = 4.2 joules, 1 Calorie (big 'c') = 4.2 kilojoules—that is, 4.2×10^3 joules. To find how many Calories (alias kilocalories) there are in one day's food intake (10 000 000 J from Table 2), simply divide 10 000 000 by 4.2×10^3. Working this out on your calculator you get 2 381, which gives 2 400 (to two significant figures). This is the sort of value that you would expect—if you know about diets! It is a sensible sort of answer.

There is a general point arising from this SAQ. The point was made that 2 400 is a 'sensible sort of answer'. It is *always, always* good practice to glance at your answer and try to see if it is sensible. If you calculate that the Moon has a mass of 5 grams or is at a distance of one metre—you've done something wrong!

SAQ 11 The answer is 546 kJ. One calorie raises the temperature of 1 g water by 1 °C. So if 1 000 g is raised 1.3 °C, then 1 300 calories are produced. But 1 calorie is 4.2 J so 1 300 calories are $4.2 \times 1\,300 = 5\,460$ J. This is 5.460 *kilo*joules. This was produced from 1 g of cake: 100 g of cake would produce 546 kilojoules. Is this a sensible answer? 546 kJ is about one-twentieth of a day's total (see item 10 of Table 4). This seems reasonable for a piece of cake.

SAQ 12 X would not equal Y; in fact, X would be greater than Y. This is because muscles are inefficient. Part of the chemical energy that they release when glucose is aerobically respired appears as heat. Only some is transferred to the bricks as gravitational energy. We do not actually know what the numbers are in this 'scene', which is why we used letters. This use of letters (it is called algebra) is discussed in Section 7.

If we choose a letter to stand for 'heat produced by muscles'—let's call it H—then we can write down an equation that is almost true in terms of the Law of Conservation of Energy. That equation is $X = Y + H$. Why only 'almost true'? We have ignored the bang (sound energy) made when each brick is put on the surface and also the slight heating in brick and surface as it is put down.

SAQ 13 $R = M + T + C + P$. The retail price is 'manufacturer's price' plus 'tax' plus 'incidental costs' plus 'profit'.

SAQ 14

(a) $D = B + C - A$

(b) $g = fs$

(c) $a = \frac{F}{m}$

(d) $Y = W + X - Z$

(e) $y = \sqrt{x - 4}$

(f) $x = y^2 - 2$

Note: the long horizontal line of the square root sign has the force of a bracket. You *can* put the brackets in if it makes you feel more comfortable.

So $\sqrt{x-4}$ means the same as $\sqrt{(x-4)}$

SAQ 15

(a) You need to multiply both sides by the denominator $t_2 - t_1$

Thus the answer is: $T_1 - T_2 = R(t_2 - t_1)$

(b) The answer is $t_2 - t_1 = \frac{T_1 - T_2}{R}$

You can get this from (a) by dividing both sides by R

(c) The answer is $T_1 = R(t_2 - t_1) + T_2$. You can get this by adding T_2 to each side of the equation that is the answer to (a).

SAQ 16

kinetic energy = $\frac{1}{2}Mv^2$ so (multiplying each side by 2)

2 × kinetic energy = Mv^2

Thus using the symbol E as in the question, $2E = Mv^2$

Now divide each side by M:

$$\frac{2E}{M} = v^2$$

Now take the square root of each side:

$$v = \sqrt{\frac{2E}{M}}$$

SAQ 17

(a) $F = Q/A$. To get the amount escaping per square metre, you need to divide the total heat loss (from the interior of the Earth) by the total surface area of the Earth.

(b) $Q = FA$ (F multiplied by A, remember).

(c) $A = Q/F$.